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Review Article

The Compatibility of Cement Bonded Fibreboard Through Dimensional Stability Analysis: A Review

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ABSTRACT

Natural fibre in cement matrix was used to reinforce, increase tensile strength, and protect against matrix cracking. The various properties of the matrix, which were introduced by the shrinkage and thermal stresses, can be attributed to the microcracks on the composites. The composites experienced significant negative changes due to the spread of microcracks. Changes in moisture have an impact on the dimensional stability of cement-bonded fibreboards. The increasing moisture content caused the expansion of cement-bonded fibreboard, whereas shrinkage was caused by the moisture being evaporated. Since natural fibres connect ineffectively with the cement matrix due to their hydrophilicity, fibre-cement composites are dimensionally unstable. Hot water treatments operate by clearing the fibre's surface of volatile compounds, impurities, and waxy elements and facilitating water absorption. Numerous variables, including the mixing ratio, the targeted density, and the pre-treatment technique used on natural fibre, influence the dimensional stability of cement-bonded fibreboard. The compatibility of cement-bonded fibreboard increases with increasing cement/fibre mixing ratio, density of cement-bonded fibreboard, hot water treatment temperature and duration.

Keywords: Cement bonded fibreboard, dimensional stability, hot water treatment, mechanical properties, physical properties

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INTRODUCTION

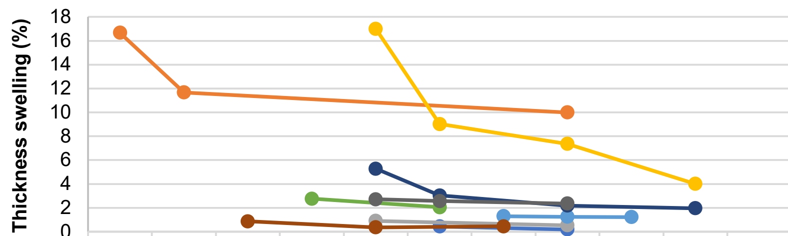
Natural plant fibres in cement composites have been shown in numerous studies to increase tensile strength, toughness, crack and impact resistance, and ductility (Zhao et al., 2019). Wax, nitrogenous materials, and inorganic salts are among the non-structural extractives that are present in the fibre (Surid et al., 2021). The structural composition is unstable because of moisture and poor adhesion in the fibre surrounding the matrix (Amin et al., 2022; Geremew et al., 2021). According to Viju and Thilagavathi (2022), hot water treatment is a cost-effective and environmentally friendly fibre modification treatment since the process simply uses fibre and water as a medium. Scapini et al. (2021) studies defined that the hot water treatment application can enhance hemicellulose dissolution, boost the yield of procedures such as enzymatic hydrolysis, and prevent the ability to recover. Many factors influenced the dimensional stability of the composite, especially the mixing ratio (Adelusi, Adedokun et al., 2019; Frybort et al., 2008), density (Adelusi, Olaoye et al., 2019; Ogunjobi, Temitope et al., 2019), and hydrophilicity of fibre that required suitable fibre treatment (Ibrahim et al., 2016; Zuraida et al., 2018). Therefore, this study will cover the compatibility of cement-bonded fibreboard correlated to dimensional stability composites.

DIMENSIONAL STABILITY ANALYSIS

Dimensional Stability of Cement Bonded Fibreboard Based on the Mixing Ratio

Frybort et al. (2008) stated that the compatible properties of the composites rely on the composition of cement and fibre. Earlier researchers have conducted numerous studies on the effect of the cement/fibre ratio on the compatibility of cement-bonded fibreboard. Atoyebi et al. (2018) mentioned that the Thickness Swelling (TS) and Water Absorption (WA) results play important roles in the dimensional stability of composite final performance. Figures 1 and 2 show the effect of different cement/fibre mixing ratios of the cement-bonded fibreboard on the TS and WA percentage values. Based on the charts, the TS and WA shared by previous researchers show the same result pattern where when the cement/fibre mixing ratio increases, the percentage mean value of TS and WA of the composites decreases (Adelusi, Adedokun et al., 2019; Adelusi, Olaoye et al., 2019; Ogunjobi, Ajibade et al., 2019; Dadile et al., 2019; Budiman et al., 2021; Fabiyi, 2004; Sotannde et al., 2012; Castro et al., 2018; Ogunjobi, Temitope et al., 2019).

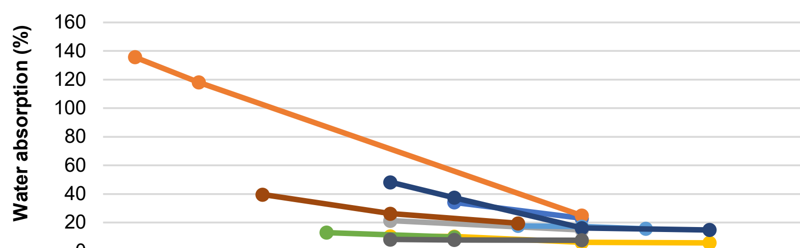
According to Figures 1 and 2, a study by Ogunjobi, Ajibade et al. (2019) found that the higher fibre content and low cement content (cement/fibre mixing ratio of 1:3) produce excessive TS (16.67%) and WA (135.76%) values. It can also be highlighted that the same mixing ratio (1:1) produces a high percentage of TS and WA values, which are 11.67% and 118.07%. The rapid changes in the TS and WA values are shown by Dadile et al. (2019) and Sotannde et al. (2012) studies, from the 2:1 and 2.5:1 mixing ratios to 3:1 and 3.5:1 mixing ratios. Based on the chart, the value of TS was found on the 2:1 mixing ratio (17% and 5.28%) and lessened drastically to the 3.5:1 mixing ratio (4.01% and 1.96%). The same goes for the WA values, which decreased from 10.29% and 48.19% to 5.86% and 14.82%. This situation is supported by Abdullah et al. (2011) and Singh et al. (2018) studies that the low cement/fibre mixing ratio causes the higher fibre to absorb more water.



	1:3	1:1	1.15:1	1.5:1	2:1	2.5:1	2.75:1	3:1	3.25:1	3.5:1	4:1
Adelusi et al. (2019)						0.43		0.19			
Ogunjobi et al. (2019)	16.67	11.67						10			
Adelusi et al. (2019)2					0.9			0.53			
Dadile et al. (2019)					17	9.02		7.36		4.01	
Budiman et al. (2021)							1.298	1.252	1.226		
Fabiyi (2004)				2.76		2.05					
Sotannde et al. (2012)					5.28	3.04		2.19		1.96	
Castro et al. (2018)			0.87		0.36		0.45				
Ogunjobi et al. (2019)2					2.71	2.57		2.36			

Cement:fibre ratio

Figure 1. Previous studies on the effect of cement/fibre mixing ratio on TS

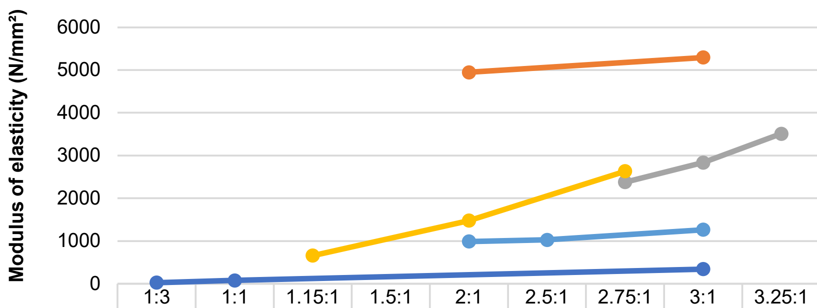


	1:3	1:1	1.15:1	1.5:1	2:1	2.5:1	2.75:1	3:1	3.25:1	3.5:1	4:1
Adelusi et al. (2019)						34.17		22.93			
Ogunjobi et al. (2019)	135.76	118.07						24.95			
Adelusi et al. (2019)2					21.3			14.8			
Dadile et al. (2019)					10.29	10.22		6.14		5.86	
Budiman et al. (2021)							17.682	17.206	15.614		
Fabiyi (2004)				13.03		9.77					
Sotannde et al. (2012)					48.19	37.47		16.14		14.82	
Castro et al. (2018)			39.56		26.24		19.43				
Ogunjobi et al. (2019)2					8.15	7.87		7.64			

Cement:fibre ratio

Figure 2. Previous studies on the effect of cement/fibre mixing ratio on WA

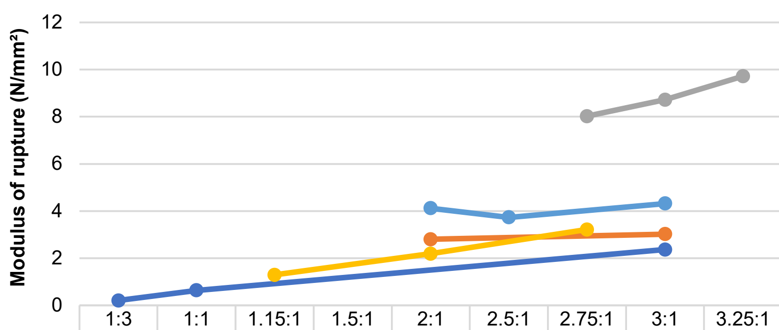
This outcome results from the materials' compatibility, which prevents void spaces from allowing the materials to absorb water. Water may not be able to enter the air void spaces because of the complete coating between the cement and natural fibre (Adelusi, Adedokun et al., 2019). Figures 3 and 4 show the previous study conducted to determine the relationship between the cement/fibre mixing ratio and the mechanical properties of cement-bonded fibreboard through Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) testing. As pictured in the charts below, each study on different mixing ratios applied produced the same conclusion: the increasing cement/fibre mixing ratio generates high mechanical performance on the composites. Comparable to the physical properties results shown above, Ogunjobi, Ajibade et al. (2019) found that the low fibre content (1:3) and same mixing ratio (1:1) resulted in the lowest MOE (23.39 N/mm² and 76.99 N/mm²) and MOR (0.20 N/mm² and 0.63 N/mm²) values. This condition shows that the cement-



	1:3	1:1	1.15:1	1.5:1	2:1	2.5:1	2.75:1	3:1	3.25:1
Ogunjobi et al. (2019)	23.39	76.99						343.12	
Adelusi et al. (2019)					4948.63			5294.3	
Budiman et al. (2021)							2377.43	2836.08	3509.41
Castro et al. (2018)			658		1477		2631		
Ogunjobi et al. (2019)2					987.73	1026.09		1262.03	

Cement:fibre ratio

Figure 3. Previous studies on the effect of cement/fibre mixing ratio on MOE



	1:3	1:1	1.15:1	1.5:1	2:1	2.5:1	2.75:1	3:1	3.25:1
Ogunjobi et al. (2019)	0.2	0.63						2.36	
Adelusi et al. (2019)					2.8			3.02	
Budiman et al. (2021)							8.02	8.72	9.72
Castro et al. (2018)			1.29		2.19		3.21		
Ogunjobi et al. (2019)2					4.12	3.73		4.32	

Cement:fibre ratio

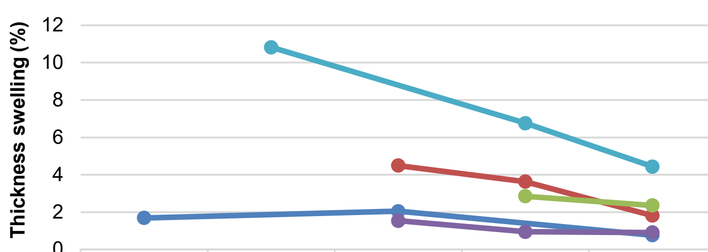
Figure 4. Previous studies on the effect of cement/fibre mixing ratio on MOR

bonded fibreboard has higher fibre content and only produces dimensionally unstable and incompatible composites.

Although each study shows different values of mechanical properties due to the type of fibre, treatment, and fabrication procedure used, the flow of high mixing ratio generates high strength composite can be analysed. The cement-bonded fibreboard with a cement/fibre ratio of 3.25:1 found by Budiman et al. (2021) reveals the higher MOE (3509.41 N/mm²), MOR (9.72 N/mm²), and IB (7.30 N/mm²) value compared to 2.75:1 and 3:1. According to Abdullah et al. (2011), the increasing fibre content will result in a decrease in compressive strength. The findings of Thong et al. (2020) shared that the flexural strength of the composite that contains a higher amount of fibre is related to a lower amount of cement matrix, which leads to a decreasing tendency of the adhesion between the fibre and cement. According to the studies, it found that the cement/fibre mixing ratio of 3.5:1 is an ideal targeted parameter in producing dimensional stable and highly compatible cement-bonded fibreboard due to the results obtained by Sotannde et al. (2012) and Dadile et al. (2019).

Dimensional Stability of Cement Bonded Fibreboard Based on Density

Limited studies have covered the effect of density on the properties of cement-bonded fibreboard. Figures 5 and 6 show earlier research studies conducted by analysing the physical properties based on the density of the composites. According to Rahim and Yunus (2021), Ridzuan et al. (2023), Ogunjobi, Temitope et al. (2019), and Nasser (2014) studies, it was discovered that the increment of cement bonded fibreboard density generates positive results on physical properties. The mean value of the TS and WA percentages decreased when the higher density was applied to the composite. Based on Figures 5 and 6, it can be highlighted that all the composite with a density of 1300 kg/m³ shows the lowest value



	900	1000	1100	1200	1300
Che Ab Rahim & Mohd Yunus (2021)	1.69		2.05		0.77
Ridzuan et al. (2023)			4.49	3.63	1.82
Ogunjobi et al. (2019)				2.85	2.36
A Nasser (2014)			1.54	0.95	0.91
Fuwape et al. (2007)		10.82		6.76	4.44

Density of cement bonded fibreboard (kg/m³)

Figure 5. Previous studies on the effect of density on TS

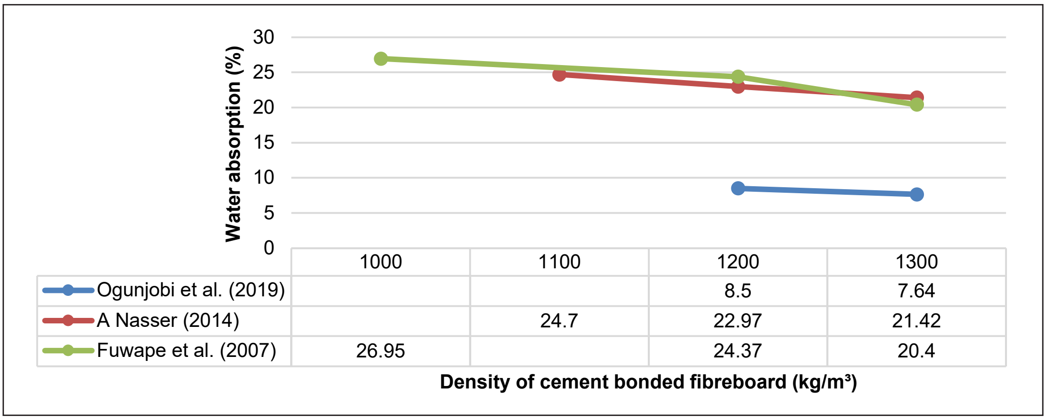


Figure 6. Previous studies on the effect of density on WA

from each study. TS results generate a major reduction from low density (1.69%, 4.49%, 2.85%, 1.54%, and 10.82%) to higher density (0.77%, 1.82%, 2.36%, 0.91%, and 4.44%). The same goes for the mean percentage value of WA, where the percentage of moisture absorbed in the composite reduced from 8.50%, 24.70%, and 26.95% to 7.64%, 21.42%, and 20.40%.

Ogunjobi, Temitope et al. (2019) found that this situation is related to the small or no void between the fibre and cement matrixes for the water to retain when the higher density is applied due to a higher board compaction ratio. The porosity in cement-bonded fibreboard decreases with the degree of coverage as density rises (Rahim & Yunus, 2021). The mechanical properties in Figures 7 and 8 also show the same constant pattern in the researcher's studies. Higher density, such as 1300 kg/m³, generates the highest MOE and MOR value. According to the bar charts, cement-bonded fibreboard with a density of 1300 kg/m³ produces high MOE and MOR, especially in a study by Fuwape et al. (2007) (5300 N/mm² and 11.55 N/mm²) and Nasser (2014) (4142 N/mm² and 12.28 N/mm²). At the same time, Yel et al. (2011) study shows a major difference between the MOE (1199 N/mm² and 2979 N/mm²) and MOR (3.45 N/mm² and 10.99 N/mm²) values between density 800 kg/m³ and 1200 kg/m³. This result clearly showed the increment of density related to the stiffness and strength of the composite.

Fuwape et al. (2007) shared that the enhancement of mechanical properties of the composites when the higher density is applied can be elaborated by the tight compaction between the fibre. Therefore, the fibre helps prevent the brittle cement from fracturing and delaying the bond-line failure, increasing the flexural stiffness of the bonded fibreboard. According to Ogunjobi, Temitope et al. (2019), a cement-bonded fibreboard with a higher density avoids hydrostatic stress against the bonds and has less or no void space for water to retain in it. It was also acknowledged that increasing board density might make heavier, stronger, and stiffer boards. This result also can be supported by Akasah et al. (2019),

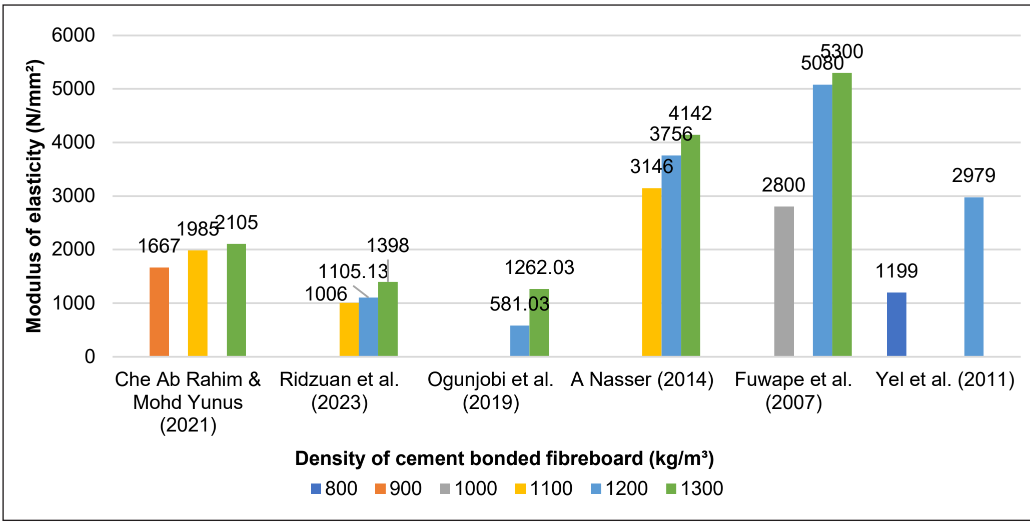


Figure 7. Previous studies on the effect of density on MOE

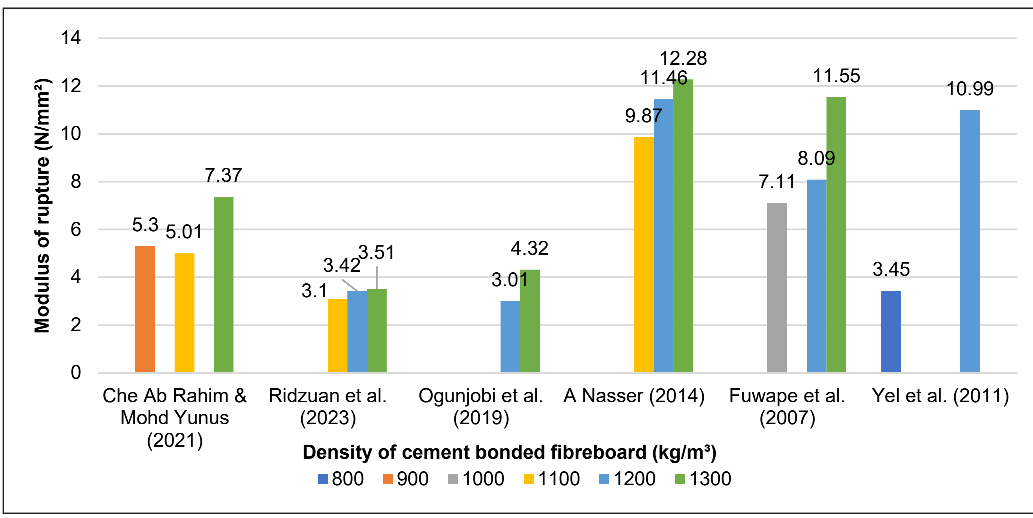


Figure 8. Previous studies on the effect of density on MOR

Maynet et al. (2023), Hassan et al. (2021), and Peter et al. (2020) studies which chose 1300 kg/m³ as the targeted density for fabricating the cement bonded fibreboard due to the optimum density in producing compatible cement bonded fibreboard.

Dimensional Stability of Cement Bonded Fibreboard Based on Hot Water Pre-treatment

According to Viju and Thilagavathi (2022), hot water treatments eliminate volatile substances, impurities, and waxy substances from the fibre's surface and improve water absorption. Figure 9 shows the scanning electron microscopy (SEM) analysis for untreated and hot water-treated fibre. Based on Figure 9, the volatile substances and extractives were removed after applying hot water treatment. The residue on the surface of untreated fibre in Figure 9(a) was seen compared to the treated fibre in Figure 9(b). Futami et al. (2021) stated that the treated fibre produced a rougher and cleaner surface, which gave an advantage for the adhesion process in cementitious composite due to the removal of lignin molecules and deposition on the fibre's surface. Momoh et al. (2020) stated that cracking occurs on the cross-section of the fibre after the hot water treatment, as shown in Figures 9(c) and 9(d) happens due to the pressure build-up from the temperature of hot water treatment (100°C) between the fibre which produces radial cracking. Figures 9(e) and 9(f) show the SEM of the fibre's cross-section with magnifications of 500×. According to Olonade and Junior (2023), the treated fibre produced more compacted lumens than the untreated fibre, which generates firmer and more stable fibre. These factors can enhance the binding between cement and natural fibre and produce composites with outstanding physical and mechanical properties.

The dimensional stability of cement-bonded fibreboard can be analysed based on the composite's physical and mechanical properties. Figure 10 shows the TS results on the cement-bonded fibreboard, which generates a major difference between the untreated and hot water-treated fibre. The relationship between the TS and hot water treatment is very clear, where the hot water treatment applied with higher temperatures produces a low TS percentage. Earlier researchers supported that the hot water treatment influences the TS

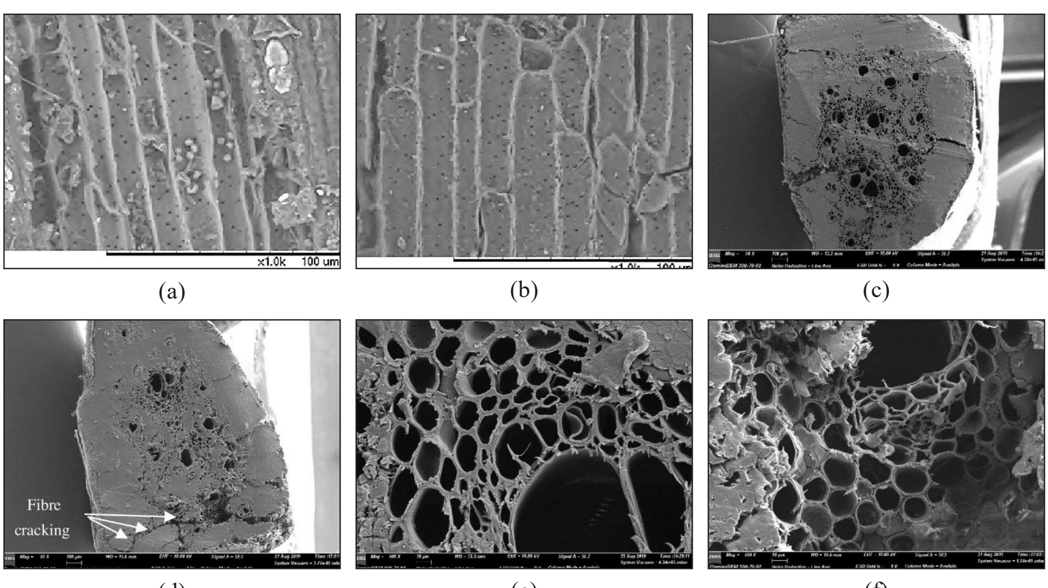


Figure 9. SEM analysis: (a) longitudinal section of untreated fibre; (b) longitudinal section of hot water treated fibre; (c) cross-section of untreated fibre 50×; (d) cross-section of hot water treated 100×; (e) cross-section of untreated fibre 500×; and (f) cross-section of hot water treated fibre 500×
Source: Cabral et al., 2018; Momoh et al., 2020

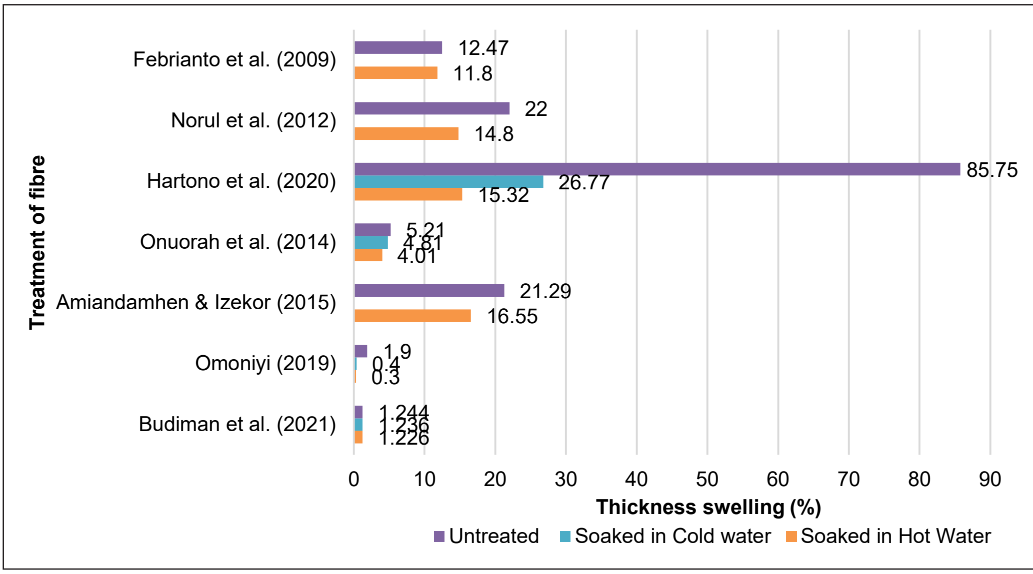


Figure 10. Previous studies on TS of cement-bonded fibreboard with untreated, cold water-treated, and hot water-treated fibre

performance of cement-bonded fibreboard whereby when the temperature of hot water treatment increases, the TS of cement-bonded fibreboard decreases (Amiandamhen & Izekor, 2015; Budiman et al., 2021; Febrianto et al., 2009; Hartono et al., 2018; Izani et al., 2012; Omoniyi, 2019; Onuorah et al., 2014).

The consistent pattern of decreasing TS performance between the untreated, cold water treated, and hot water treated fibre is remarked. The untreated fibre has the highest value of TS compared to the treated fibre, which is the fibre soaked in hot water and has the lowest value of TS. Izani et al. (2012) highlighted that the reduction of TS is related to the degradation of hemicellulose and lignin content during hot water treatment, where these substances have a high ability for water absorption. The low percentage of TS value shows that the cement-bonded fibreboard is sturdy where the composites do not easily swell and absorb water. Therefore, the removal of the hydroxyl group is related to the swelling of the cement-bonded fibreboard. These show that the hydroxyl group in the fibre was ultimately removed when the fibre was soaked in hot water.

Earlier studies had discovered the relationship between the WA of cement-bonded fibreboard and the effect of the application of hot water-treated fibre compared to untreated fibre. Based on the results of the previous study, as shown in Figure 11, it was found that the higher the temperature of hot water treatment applied, the lower the WA percentage value recorded (Amiandamhen & Izekor, 2013; Amiandamhen & Izekor, 2015; Budiman et al., 2021; Febrianto et al., 2009; Izani et al., 2012; Omoniyi, 2019). Budiman et al. (2021) and Omoniyi (2019) displayed that the fibre treated with cold water (16.774% and 14.6%) has a slightly lower WA percentage value than the fibre soaked in hot water (15.614% and

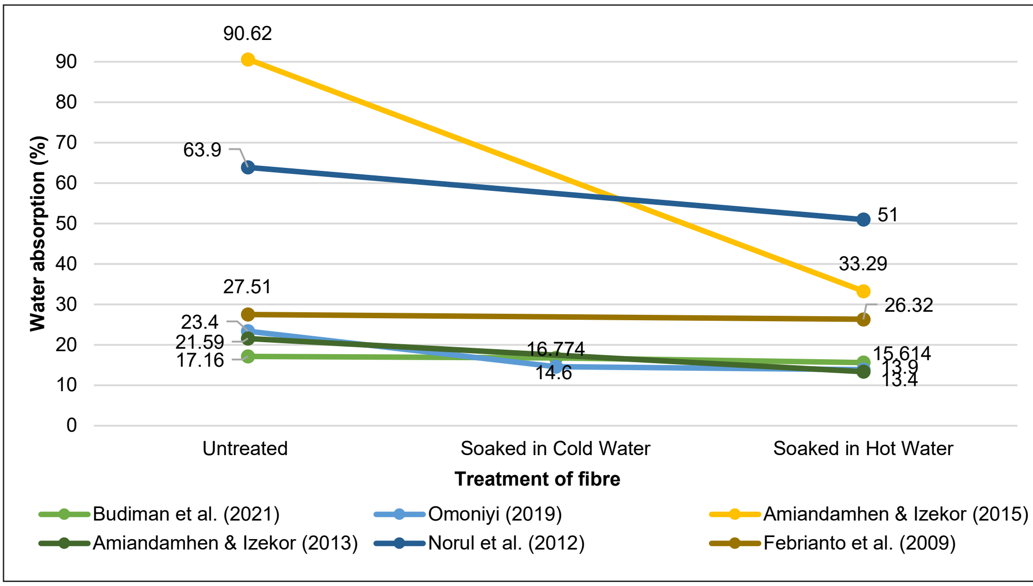


Figure 11. Previous studies on WA of cement bonded fibreboard with untreated, cold water treated, and hot water treated fibre

13.9%) with a temperature of 100°C. Eventually, the reduction of WA percentage value in the cement-bonded fibreboard is related to the adhesion between the matrix and fibre after treatment, leading to the presence of capillaries (pores) that had a high suction effect on the composite structure for better bonding (Halip et al., 2019).

For cementitious composites, the amount of WA decreases as the TS value decreases. The reduction of TS and WA generates more dimensional stable cement-bonded fibreboard by enhancing the bonding between the fibre and cement (Amiandamhen & Izekor, 2015). The higher the temperature of hot water applied to the fibre, the higher the content of extractive substances removed. Removing lignin and hemicellulose from the fibre helps the binding composites penetrate easily and improves the adhesion between the fibre and cement. The water molecules are unable to be absorbed in the fibre easily because it is covered with cement. However, the water is still able to penetrate between the fibre pores due to the capillary effect (Zalinawati et al., 2020). The presence of water in the cell wall can also be carried in the bonding tissues of composites (Hartono et al., 2018).

It was noticed through the earlier research shown in Figures 12 and 13 that there is a similar pattern where the cement-bonded fibreboard pre-treated with hot water has a higher MOE and MOR value compared to the untreated fibre. The untreated fibre of cement bonded fibreboard had a mean value in a range of 10.3 N/mm² to 9111 N/mm² (MOE) and 0.45 N/mm² to 50.12 N/mm² (MOR) compared to the hot water treated fibre which shows higher range value 1275.75 N/mm² to 14736 N/mm² (MOE) and 2.31 N/mm² to 67.89 N/mm² (MOR). This situation can be related to the study of Zheng et al. (2023), whereby the treatment applied to fibre led to an improvement in MOE (stiffness) and MOR (strength) of the cement-bonded fibreboard. The increased crystallinity in fibre, removal of extractive, and rearrangement of cellulose molecules after the treatment increased the fibre's stiffness and generated high flexural properties. The treated fibre and cement matrix leads to higher strength and more rigid composite due to improved linking structures.

Figure 14 shows earlier studies' internal bonding (IB) results, which compare untreated and hot water-treated fibre in cement-bonded fibreboard. A similar trend was observed according to the IB mean value where the hot water treatment improves the

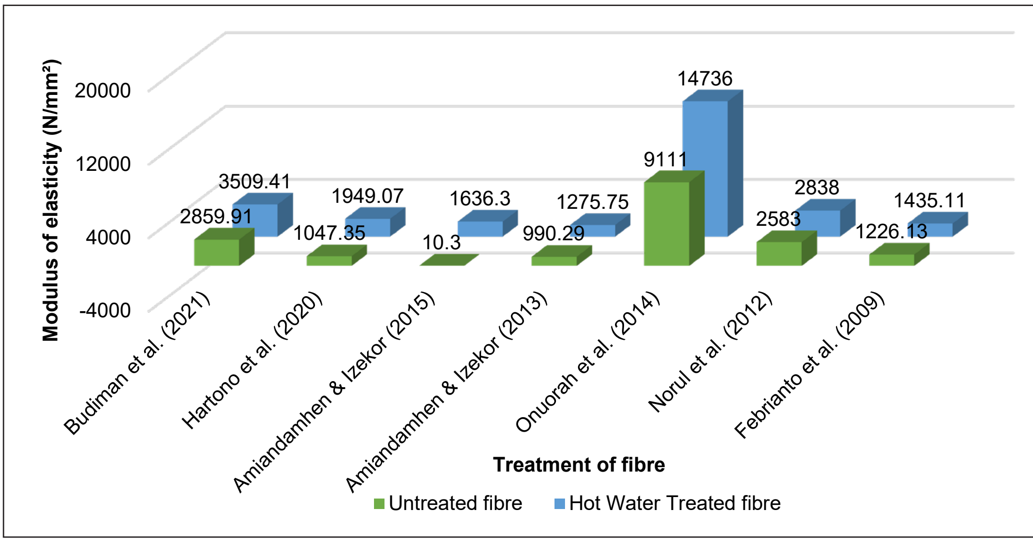


Figure 12. Previous studies on MOE of cement-bonded fibreboard with untreated and hot water-treated fibre

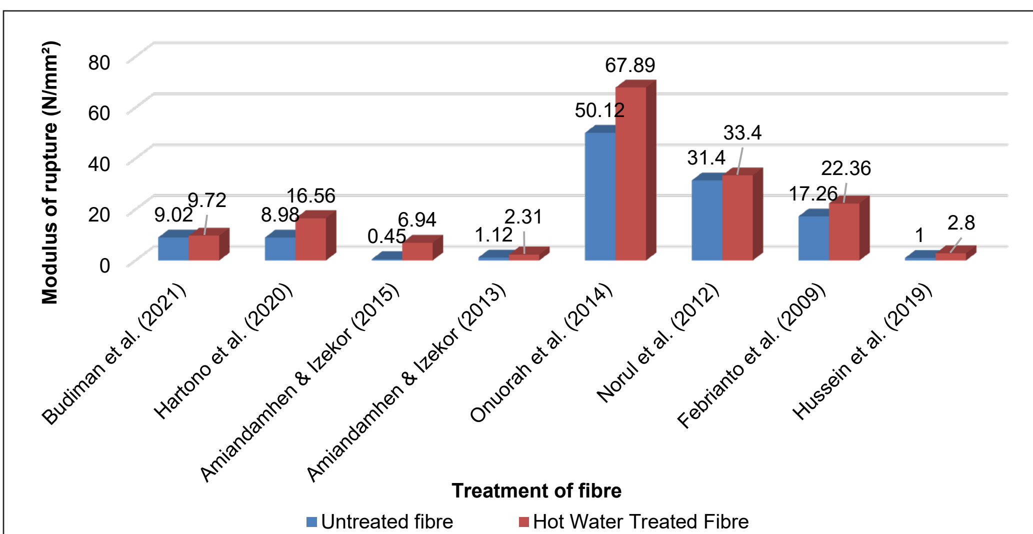
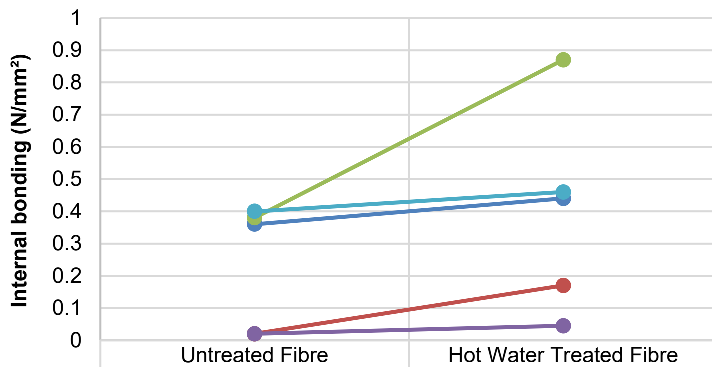


Figure 13. Previous studies on MOR of cement-bonded fibreboard with untreated and hot water-treated fibre



	Untreated Fibre	Hot Water Treated Fibre
Hartono et al. (2020)	0.36	0.44
Amiandamhen & Izekor (2015)	0.02	0.17
Norul et al. (2012)	0.38	0.87
Hussein et al. (2019)	0.02	0.045
Febrianto et al. (2009)	0.4	0.46

Figure 14. Previous studies on IB of cement-bonded fibreboard with untreated and hot water-treated fibre

mechanical properties of composites through internal bonding ability (Amiandamhen & Izekor, 2015; Febrianto et al., 2009; Hartono et al., 2018; Hussein et al., 2019; Izani et al., 2012). Amiandamhen and Izekor (2015) explained that the positive results from hot water treatment on fibre are related to the fibrillation of the fibre surface throughout the treatment process, creating great bonding on the fibre and matrixes. The hot water treatment helps enhance the mechanical properties of composites caused by fibre particle properties and changes in chemical composition (Iswanto et al., 2018). The strength of the matrix interlocking may decrease as extractive content rises. The reduced mechanical strength was also caused by increased adhesive failure due to the increased extractive level (Hartono et al., 2018).

It is proven by previous studies on physical and mechanical performance that the hot water treatment is an effective treatment that can be applied to the fibre to produce more dimensionally stable and compatible cement-bonded fibreboard. Omoniyi (2019) found that the cement-bonded composites pre-treated with 100°C of hot water produced more compatible results compared to fibre treated with 60°C of hot water, cold water, and untreated fibre. Based on the outcome, the compatibility of the composite is shown by the reduction of WA and TS values from untreated fibre to the hot water-treated fibre with the highest temperature. The untreated fibre generates the highest mean value of WA and TS (23.4%–26.2% and 1.9%– 2.5%), while the cold water-treated fibre produces 14.6%–17.9% of WA and 0.4%–0.9% of TS. When the fibre was treated with hot water, the WA and TS decreased, followed by the temperature where 14.2%–16.2%, 0.3%–0.6% for 60°C of hot water and 13.9%–15.4%, 0.3%–0.6% for 100°C.

Most researchers are using hot water treatment with a temperature of 100°C as a pre-treatment method to remove the water-soluble sugar and hemicellulose in producing more compatible and dimensional stable cement bonded fibreboard (Amiandamhen et al., 2021; Dadile et al., 2019; Hassan, 2018; Ogunjobi, Ajibade et al., 2019). Other researchers' application and performance results of hot water treatment at 100°C have supported Omoniyi's (2019) research that this temperature is the optimum temperature for stable and high-strength composites. The duration of the pre-treatment method also played an important role in removing the extractives and hemicellulose content from the fibre surface. Drpić et al. (2022) conducted a study of the difference in time applied (30 minutes and 60 minutes) in using the hot water treatment (100°C) on a wooden chip. According to the findings, the cellulose content of the wooden chip after the hot water treatment for 60 minutes is 48.68%, which is increased compared to 30 minutes (47.61%) and untreated wooden chips (46.12%).

The increase of cellulose content for wooden chips treated with hot water for 60 minutes was discussed, resulting from the lower degradation reactions of wood tissues. Elmoudnia et al. (2023) also found that the fibre treated with hot water for 60 minutes has the highest crystallinity index than those treated for 15 and 30 minutes. In addition, the fibre treated for 60 minutes produced a rough surface, which demonstrated the elimination of amorphous components (Elmoudnia et al., 2023). Based on the mentioned studies, it can be found that higher temperature and duration of hot water treatment on fibre helps remove higher extractive content and increase the cellulose content, which benefits composite performance. Therefore, hot water treatment with controlled temperature and duration, such as 100°C for 60 minutes, is the ideal parameter that can be applied to produce compatible and dimensional stable cement-bonded fibreboard.

CONCLUSION

The dimensional stability of cement-bonded fibreboard is influenced by many factors, mainly the mixing ratio, the targeted density, and the method of pre-treatment of natural fibre. The higher mixing ratio and density produced a more compatible cement-bonded fibreboard. Based on the review, the mixing ratio of cement/fibre is 3.5:1, and a targeted density of 1300 kg/m³ may produce a compatible cement-bonded fibreboard. The other important aspect of dimensional stability in cement-bonded fibreboard is the natural fibre treatment method. The hot water treatment is the most sustainable, environmentally friendly, and cost-effective treatment compared to the other methods. The reviews show that the higher the temperature and duration applied to the hot water treatment, the higher the compatibility of cement-bonded fibreboard. The temperature of 100°C and 60 minutes of treatment are the ideal parameters for conducting the hot water treatment for producing cement-bonded fibreboard.

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