sustainability

MDPI

Review

Recent Progress in the Application of Coconut and Palm Oil Fibres in Cement-Based Materials

Erika Futami [1], Payam Shafigh [1,*], Herda Yati Binti Katman [2,*] and Zainah Ibrahim [3]

[1] Centre for Building, Construction & Tropical Architecture (BuCTA), Faculty of Built Environment, Universiti Malaya, Kuala Lumpur 50603, Malaysia; s2016868@siswa.um.edu.my
[2] Department of Civil Engineering, Universiti Tenaga Nasional (UNITEN), Jalan IKRAM-UNITEN, Kajang 43000, Malaysia
[3] Department of Civil Engineering, Faculty of Engineering, Universiti Malaya, Kuala Lumpur 50603, Malaysia; zainah@um.edu.my
* Correspondence: pshafigh@um.edu.my (P.S.); Herda@uniten.edu.my (H.Y.B.K.)

Abstract: Cementitious materials are widely used in the construction industry. These materials have high compressive strength and huge environmental effects but low tensile and flexural strength. Thus, researching these materials to make them environmentally friendly is very important in terms of the sustainable development of the construction industry. In recent years, the amount of research about cementitious composites reinforced with natural fibre has increased annually. This review paper was presented to understand the latest research progress on these fibres and the needs of future research to encourage the construction industry to apply these materials. The optimum dosage of natural fibre depending on the purposes can improve the physical, mechanical and thermal properties of cementitious composites, and natural fibre is highly expected to become an alternative material of synthetic fibres, such as steel, plastic and carbon fibre.

Keywords: natural fibre; cement-based materials; composites; sustainable materials; mechanical properties; durability; thermal properties

check for updates

Citation: Futami, E.; Shafigh, P.; Katman, H.Y.B.; Ibrahim, Z. Recent Progress in the Application of Coconut and Palm Oil Fibres in Cement-Based Materials. *Sustainability* **2021**, *13*, 12865. https://doi.org/10.3390/su132212865

Academic Editor: Munjed A. Maraqa

Received: 28 August 2021
Accepted: 13 October 2021
Published: 20 November 2021

1. Introduction

Cement-based materials, such as concrete and mortar, are widely used in the construction industry. In general, cement-based materials have high compressive strength but much lower tensile and flexural strength [1]. For use as building materials, reinforcing these resources with other materials is required to improve their tensile strengths. Nowadays, steel rebar is widely used as a reinforcing material in the construction industry. Steel and cementitious materials are an excellent combination for carrying tensile and compression stresses because the properties of steel are opposite those of cementitious materials in tension [2]. Another approach of cementitious material reinforcement is fibre reinforcing using synthetic fibre, such as steel and plastic [3]. Fibre reinforcement allows the omission of rebar arrangements at a construction site. In addition, this method can prevent the expansion of cracking because short fibres are distributed evenly inside the cement matrix. However, synthetic fibres experience problems, such as discharging plenty of carbon dioxide, being heavyweight and having high costs [4]. In recent years, in terms of environmental protection and achieving low-cost housings, the research of using natural fibres as an alternative material to synthetic fibres for reinforcement materials is increasing annually [5–7].

Natural fibre is defined as a hairlike raw material that is directly obtainable from a vegetable, animal or mineral source [8]. Examples include bamboo, coconut, palm oil, straw, sisal or jute. These natural fibres have already been used in different industries. For instance, the automotive industry is one of the industries that began the use of natural fibres as a part of automotive products at an early age. According to Mase [9], kenaf fibre was implemented as a binder material of the door trim substrates of motor vehicles for the first time in 1999. In their study, Daniyan et al. [10] stated that palm oil could be an environmentally friendly corrosion inhibitor for steel and iron. They also highlighted that the demands of vegetable-based oils will increase due to growing environmental concerns. That is, the amount of industrial waste, such as coconut and palm oil fibre, also increases. Therefore, effective recycling methods must be proposed for the sustainable development of the palm oil and construction industries. Many studies about the application of natural fibres in different industries, such as fabric products, biomass fuels, fertilisers or heat-insulating materials, have been published [11]. Regarding the construction industry, historically, straw fibre has been used to reinforce adobes [12]. In 1981, Castro and Naaman [12] studied cement-mortar reinforced with natural fibre. They revealed that natural fibre had an eligible mechanical property as that of reinforcement materials. In recent years, there have been some research studies on applications of coconut and palm oil fibres such as wall panelling systems [13], wall insulation [14], cement boards partition [15], slabs [16], tiles bricks, internal and external wall, cabinet [17], hollow blocks [18], and wall coating for improving thermal properties [19]. However, no examples of the practical use of natural fibres in the construction industry and evidence that natural fibres have a high potential in terms of physical and mechanical properties are provided.

The main component of natural fibres is cellulose, hemicellulose and lignin [20]. Cellulose mainly takes a role of function of toughness inside natural fibres. Hemicellulose and lignin work as bonding materials of cellulose. They have great potential for building material applications because natural fibres have good physical, mechanical and durability properties [21]. The bridging effect is the most remarkable advantage of natural fibre when used as reinforcement materials for cementitious materials [22]. Although natural fibres cannot avoid the occurrence of the cracking of the matrix, they can prevent the cracks of the matrix from flaking and expanding. The main factors of the degree of this effect include the fibre and bonding strength between the fibre and cement matrix [23]. Bonnet-Masimbert et al. [23] held a natural fibre pull-out test to investigate the interfacial strength between cement and natural fibre. The result showed that well-treated natural fibre had a better bridging effect than untreated ones. They concluded that the main factors of the bridging effect include the bonding strength of the interface between cement and natural fibre and the natural fibre's strength itself. Ozerkan et al. [24] researched the mechanical properties of different ratios of palm oil fibre. The optimum dosage of natural fibre improved the compressive strength. However, excessive fibre reduced the compressive strength inversely. Ferdiansyah and Razak [25] investigated the strength and durability of black sugar palm fibre-reinforced concrete. More than 0.6% of natural fibre contributed to improving the concrete toughness. They also reported that a longer and higher amount of natural fibre is clustered when it is mixed with cement matrix; thereby, achieving a random distribution of fibre in the wet mix becomes difficult. However, the strength and durability decreased at later ages because the natural fibre deteriorated over time. As another feature, natural fibres have high water absorption [26]. This factor enables natural fibres to have a porous structure. Natural fibres absorb excessive water inside the cement matrix at the initial hardening stage and gradually release the water. Hence, it can also prevent the drying shrinkage caused by the evaporation of excess water [27]. However, the high water absorption of natural fibre reduces the workability of the cement matrix [28]. According to Momoh and Osofero [29], natural fibre absorbed water inside the matrix and worsened the workability. Furthermore, natural fibres absorb excessive water inside the cement matrix at the initial hardening stage, thereby preventing drying shrinkage, which was caused by evaporation. In addition, natural fibres gradually release water, so it is also good for cement hydration at a later time. As another disadvantage of natural fibre, it tends to negatively affect its own mechanical properties with time. According to the research of Momoh and Osofero [1], the strength of natural fibre reinforced concrete was reduced by the passage of time and tended to be more obvious for a higher percentage of oil palm fibres

(OPFs). They explained that this strength loss of specimens was due to the degradation of the surface of palm oil fibre that is in contact with the alkaline concrete matrix.

In terms of thermal properties, natural fibre reinforced cement-based materials generally exhibited good thermal properties [30] because of two reasons. Firstly, natural fibre itself has a good thermal property because of its porous structure. Secondly, when the natural fibres are added into the mixtures, they contain huge amounts of air voids in the cement matrix. Quiñones-Bolaños et al. [19] investigated the thermal properties of low-income housing structures coated by a coconut fibre added cement-based mortar. The results showed that the addition of mortar in coconut fibre had the potential to double the specific heat value and decreased thermal conductivity by approximately 80% compared with conventional mortar. Based on these studies, that the effectiveness of adding natural fibre into cement-based materials under certain conditions is proven. However, these studies used binder-rich mix proportions. Low-grade cement-based materials are also used in the construction industry. Shafigh et al. [31] investigated the mechanical and thermal properties of cement mortar with different proportions. They revealed that low cement content mixture samples had good thermal properties because more air voids existed than higher cement content samples.

Natural fibres, such as coconut and palm oil fibres, are locally available in Malaysia and other tropical regions. Due to the numerous engineering and environmental advantages of using these fibres in cement-based materials and because of the lack of knowledge on these types of natural fibres compared with synthetic ones, this review paper was provided to understand the latest progress of research on these fibres and the needs of future research to encourage the construction industry to apply these materials.

2. Properties of Coconut and Palm Oil Fibres

2.1. Coconut Fibre

Coconut fibre is extracted from the outer shell of the coconut. Its colour is mostly brown (Figure 1). Coconut fibres are cut into appropriate lengths depending on its application [28]. Generally, the advantages of coconut fibres include its toughness and durability, resilience, resistance to fungi and rotting, providing excellent insulation against temperature and sound and it is not easily combustible compared with other natural fibres [17]. Coconut fibre mainly consists of cellulose, hemicellulose, lignin and ash. Table 1 shows the chemical compositions of coconut fibre from different researchers. According to Ramakrishna and Sundararajan [32], the cellulose, hemicellulose and lignin contents of this fibre are 33.2%, 31.1% and 20.5%, respectively. These results agree with the report of John et al. [33] and Hill et al. [34]. In John et al. [33], the fraction of hemicellulose was 11.6–21%, and those of cellulose and lignin were a maximum of 60% and 45%, respectively. According to John et al. [33] and Ngadiman et al. [35], the ash contents are approximately 2.2% to 8.1%. Cellulose seems to be the main component of coconut fibre. Natural fibres that contain cellulose and lignin are called lignocellulosic fibre. Figure 2a,b shows the SEM morphologies of coconut fibre. Many pores are observed on the surface and inside the coconut fibre [28].

Bui et al. [20] reported the micromorphology of coconut fibre. Figure 3 shows the surface and cross-section of coconut fibres that were taken by using a digital microscope. Coconut fibres have a porous structure and rough surface, and most fibres do not have a circular cross-section. They have also conducted a survey of the diameter of 300 raw coconut fibres by the image analysis method and indicated that the average diameter in two directions at the right angle ranges from 0.090 to 0.39 mm (Figure 4). As a physical property, the absolute density of the raw coconut fibre is approximately 1.41 g/cm^3, and this value is lower than those of some reinforcement materials, such as steel fibre (7.80 g/cm^3), carbon fibre (1.75 g/cm^3) or glass fibre (2.55 g/cm^3).

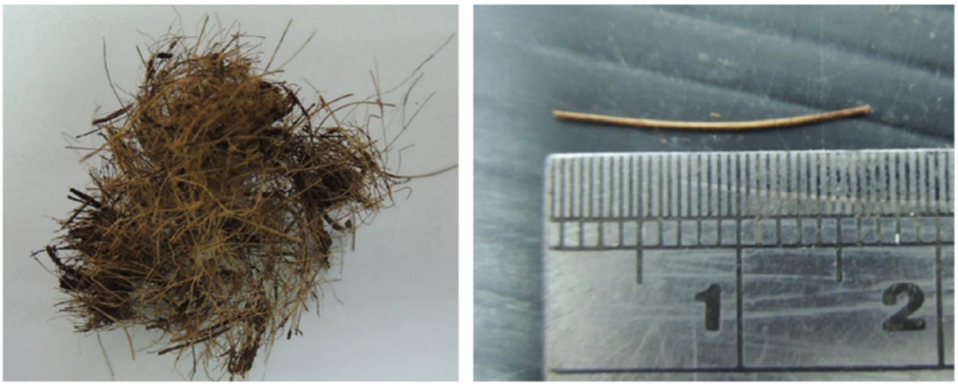
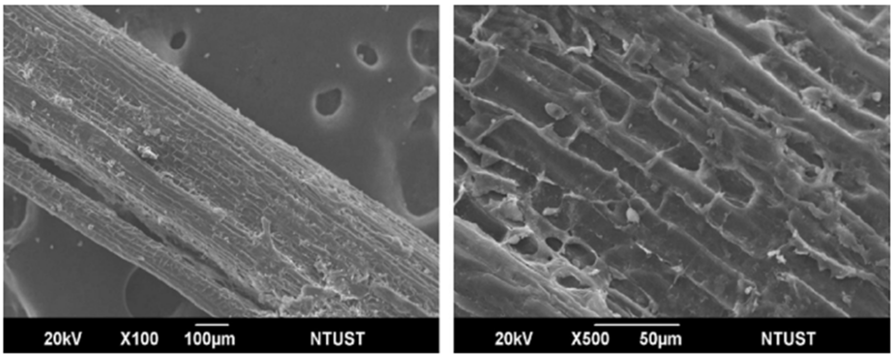


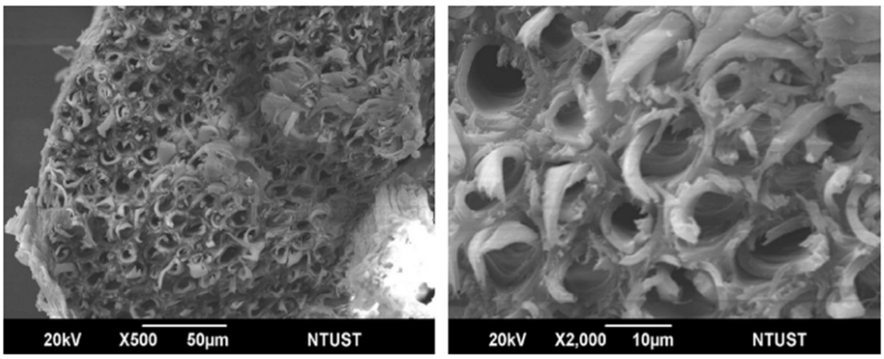
Figure 1. Extracted raw coconut fibres (**Left**) and example of length of coconut fibre (**Right**). Reprinted from [28] with permission of Elsevier, 2016.

Table 1. Chemical compositions of coconut fibre (%).

Reference	Cellulose	Hemicellulose	Lignin	Pentosan	Ash	Silica
[36]	33.2	31.1	20.5	-	-	-
[33]	43–60	11.6–21	27.7–45	-	3.9–8.1	-
[34]	35–47	28–15	20–31	-		-
[35]	-	-	32.8	-	2.2	-



(**a**)



(**b**)

Figure 2. SEM morphologies of coconut fibre: (**a**) SEM morphologies of the surface of coconut fibre and (**b**) SEM morphologies of the cross-section of coconut fibre. Reprinted from [28] with permission of Elsevier, 2016.

Figure 3. Digital microscope images of coconut fibre: (**a**) surface of coconut fibre and (**b**) cross-section of coconut fibre. Reprinted from [20].

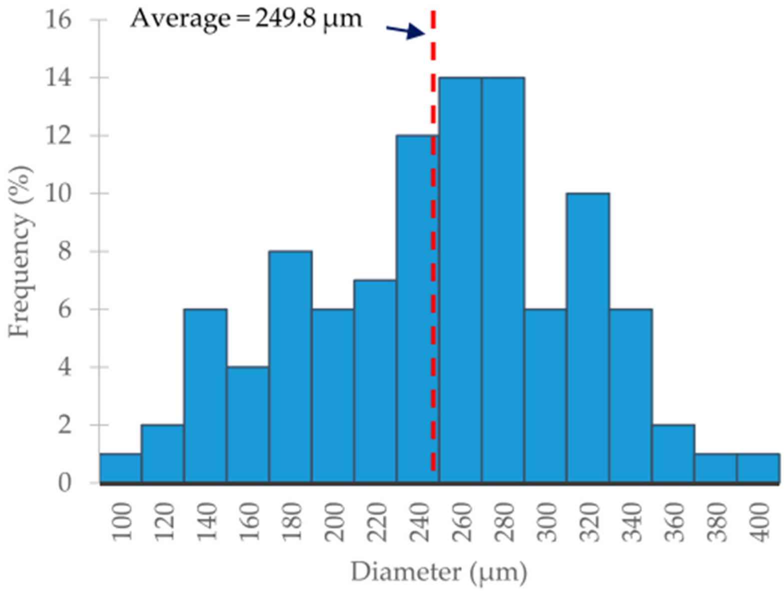


Figure 4. Diameter distribution of raw coconut fibres. Reprinted from [20].

Table 2 shows some physical and mechanical properties of coconut fibres. One of the remarkable properties of coconut fibre is elongation. According to Femandez [37], the elongation of coconut fibre is 30% whilst those of other natural fibres, such as sisal and jute, are only 2–5% and 1.5–1.8%, respectively. This finding means that coconut fibre would have higher durability and strength properties than other natural fibres. Ramakrishna and Sundararajan [32] reported that coconut fibre marked the elongation maximum to 75%. Femandez [37] reported the Young's modulus of coconut fibre to be 4000–6000 MPa. Tensile strength could be seen as a huge difference in one study for different samples and reports. For example, Ramakrishna and Sundararajan [32] reported that the tensile strength of coconut fibre was 15–327 MPa. Rao and Rao [38] reported that the tensile strength was 500 MPa. This value is the same as that for the modulus of elasticity. Ramli et al. [39] reported that the modulus of elasticity is 22,400 MPa, whilst Agopyan et al. [40] reported it to be 2800 MPa. The inconsistent and unstable values of the different properties of natural fibres are amongst the problems that affect the qualities of natural fibre and therefore caused the construction industry to be hesitant of using them in a wide range of products.

Table 2. Physical and mechanical properties of coconut fibre.

Reference	Diameter (mm)	Length (mm)	Density (g/cm^3)	Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Elongation at Break (%)	Water Absorption (%)
[20]	0.25		1.41				77.82
[37]			1.2	175	4000–6000	30	
[32]	0.40–0.10	60–250		15–327		75	
[38]			1.2	500			
[39]	0.32	20–30			22,400		
[40]	0.21		1.1–1.4	107	2800	37.7	93.8–161.0

2.2. Oil Palm Fibre

Palm oil fibre can be extracted from many different parts of an oil palm tree, such as in the trunk, leaves, fruit bunch and mesocarp, as shown in Figure 5 [29]. The colour of fibre after preparation is mostly brown. Fibres are discharged from the palm oil industry as industrial wastes. A few parts of wasted fibres could be used as the fertilizer of oil palm plantations; however, most of them are just discarded. Table 3 shows the chemical composition of palm oil fibre. According to Khalil et al. [41], palm oil fibre mainly contains 49.6% of cellulose, 18% of hemicellulose, 21.1% of lignin, 17.8% of pentosan and 2% of ash. These values approximately matched with the report of Lertwattanaruk and Suntijitto [42]. They reported that the percentage of lignin, pentosan and ash was 29.8%, 14.4% and 2.65%, respectively. Bonnet–Masimbert et al. [23] mentioned that the percentage of silica was 1.8%. In oil palm fibres, as well as most other natural fibres, the cellulose and the hemicellulose are bonded in a lignin matrix [29]. Figure 6 shows the microscopic images of the surface and cross-section of palm oil fibres. These images clearly show that many porosities exist on the surface and inside of the palm oil fibre.

Table 3. Chemical compositions of palm oil fibre (%).

Reference	Cellulose	Hemicellulose	Lignin	Pentosan	Ash	Silica
[41]	49.6	18	21.1	17.8	2	-
[42]	-	-	29.8	14.4	2.65	-
[23]	42.7–65	17.1–33.5	13.2–25.31	17.8–20.3	1.3–6.04	1.8

Similar to coconut fibre, palm oil fibre also has good physical and mechanical properties. Table 4 shows the report of the physical and mechanical properties of palm oil fibre from different researchers. According to Ahmad and Mohd Noor [44] and Dawood and Ramli [43], the size of palm oil fibres was within 0.021–0.7 mm with a length ranging from 30 to 40 mm, the density was 0.7–1.51 g/cm^3 [23], and the modulus of elasticity was 2500 MPa [25] to 32,000 MPa [45]. The elongation at break was 1.24–18% [23,43]. Table 4 shows a huge difference between the test results of different properties. For example, Ahmad and Mohd Noor [44] reported that the water absorption of palm oil fibre was 60%, whilst Ferdiansyah and Razak [25] reported that it was 0.5%. In terms of tensile strength, a huge difference was observed in each study. Abdullah et al. [46] reported that the tensile strength of this fibre was 300–600 MPa, whilst Dawood and Ramli [43] reported that it was 21.2 MPa. The quality of natural fibre is not uniform, and the properties of palm oil fibre depend on which part of the oil palm tree the fibre was extracted from. Overall, oil palm fibre has strong mechanical properties to be used as a fibre reinforcement material. Therefore, oil palm waste fibre is expected to be used as the sustainable and eco-friendly alternative material of synthetic fibres in the construction industry.

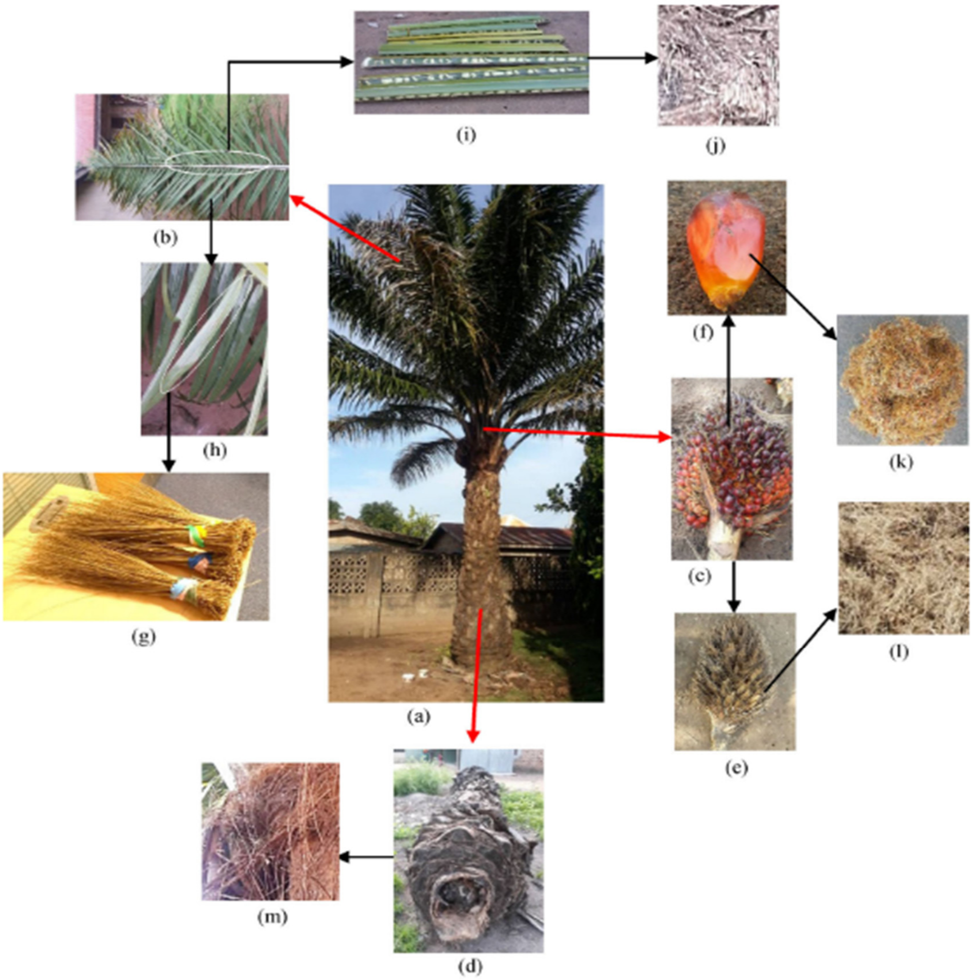


Figure 5. Different types of oil palm fibres (OPF): (**a**) oil palm tree; (**b**) leaf; (**c**) fruit; (**d**) trunk; (**e**) empty fruit bunch; (**f**) dissected oil palm fruit; (**g**) oil palm broom fibres; (**h**) oil palm leaflet; (**i**) oil palm frond; (**j**) oil palm frond fibres; (**k**) oil palm mesocarp fibres; (**l**) empty fruit bunch fibres; (**m**) oil palm trunk fibres. Reprinted from [29].

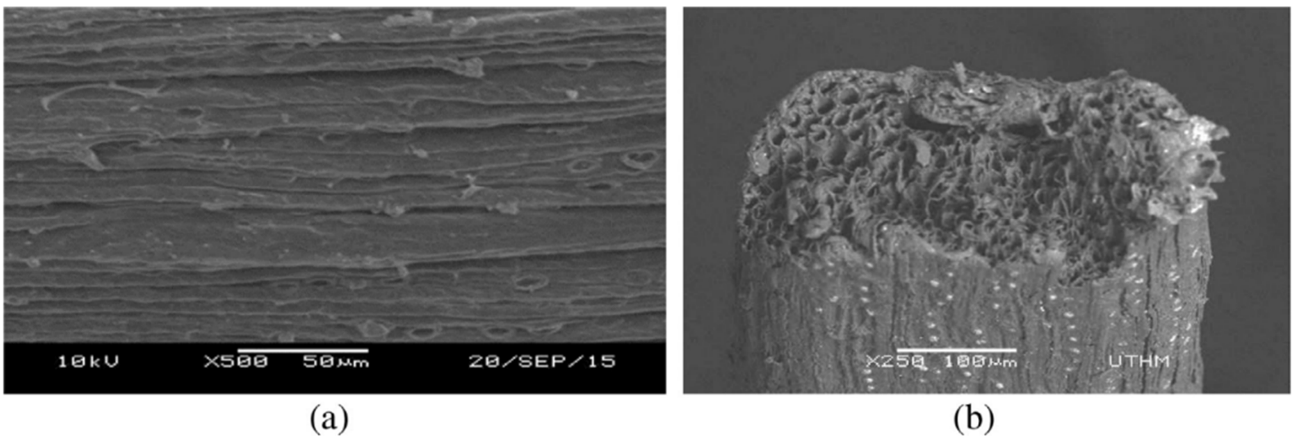


Figure 6. SEM morphologies of palm oil fibre. (**a**) Surface and (**b**) cross-section. Reprinted from [43].

Table 4. Physical and mechanical properties of palm oil fibre.

Reference	Diameter (mm)	Length (mm)	Density (g/cm^3)	Tensile Strength (MPa)	Module of Elasticity (MPa)	Elongation at Break (%)	Water Absorption (%)
[44]	0.2–0.7	40	-	-	-	-	60
[43]	0.021	30	-	21.2	-	1.24	0.6
[46]	-	-	1.2	300–600	-	-	-
[25]	0.3–0.5	-	-	-	2500–3000	2–5	0.5
[23]	-	-	0.7–1.51	25–550	500–9000	4–18	-
[22]	-	-	1.10	300–600	15,000–32,000	-	-

3. Preparation and Pre-Treatment Methods for Coconut and Palm Oil Fibres

As the first step of preparing coconut fibres, the coconut husks are steeped in hot water, and then the fibres are removed from the husk by combing and crushing. At this time, this coconut fibre is called raw fibre [47]. To be used as the reinforcement material, the coconut fibre must be washed with clean water three times and dried in the oven at a temperature of 40 °C for 12 h. For the boiling treatment, the fibres were boiled for 2 h and washed until the water became clean. Subsequently, they were dried in the oven at 40 °C for 12 h. The full process of coconut fibre preparation is illustrated in Figure 7, as reported by Bui et al. [20]. They also reported that boiling and alkaline treatment for fibres improved the fibre's mechanical strength. Figure 8 shows the digital microscopic images of the surface and cross-section of untreated and treated coconut fibres. Figure 8a,a′,b,b′,c,c′ shows raw fibre, alkali-treated fibre and boiled fibre, respectively. As seen, treated fibres have less cross-section area and more porous structure than untreated fibre.

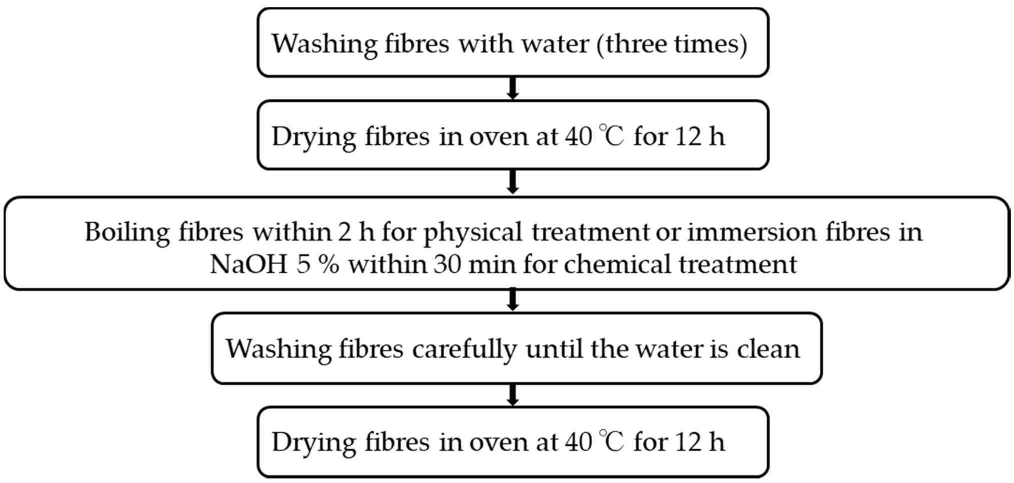


Figure 7. Process of fibre treatment applied. Reprinted from [20].

Lertwattanaruk and Suntijitto [42] introduced a pre-treatment method for coconut and palm oil fibres in their report. Initially, they cut the fibres into a length of 5–10 mm. Then, these fibres were washed with water until the pH became approximately 7. Next, they were boiled for 2 h in hot water to reduce water-soluble chemicals. Then, coconut fibres were oven-dried at 100 °C for 24 h. After this drying process, the fibres were ready to be used in the mixtures. Many researchers recommended performing a pre-treatment for natural fibre before containing natural fibre into the cementitious composites. Preparation influences the properties of natural fibres and bonding strength between the natural fibre and cement matrix greatly. Bonnet-Masimbert et al. [23] analysed the effect of alkaline treatment for palm oil fibre. The fibres were treated with two different concentrations of NaOH (1% and 10%) and three different soaking times (i.e., 2, 6 and 24 h). Then, the fibres were washed several times with water and then dried at 60 °C for more than 24 h. Figure 9 shows the surface of untreated and treated palm oil fibres taken by a scanning electron microscope (SEM). In Figure 9d,f, these particles are silica, which are commonly found at the surface of oil palm fibre. The longer the soaking time is, the greater the number of holes that are opened due to the removal of silica. By analysing the SEM morphologies, the 2 and 6 h treatments removed 6% and 8% of the silica, respectively. Moreover, the 24 h treatment is significantly more effective because it could remove 55% of silica. Pre-treatment causes natural fibres to have a more porous and rougher surface texture because of this reason. A tensile stress test was also conducted. According to the result, a significant improvement for 1% NaOH treatment fibre cannot be observed. Furthermore, the fibres that were treated with 10% NaOH solution for 6 h increased their tensile strength by approximately 1.4 times than the untreated fibre. However, soaking the material into 10% NaOH solution for 24 h reduced the tensile strength.

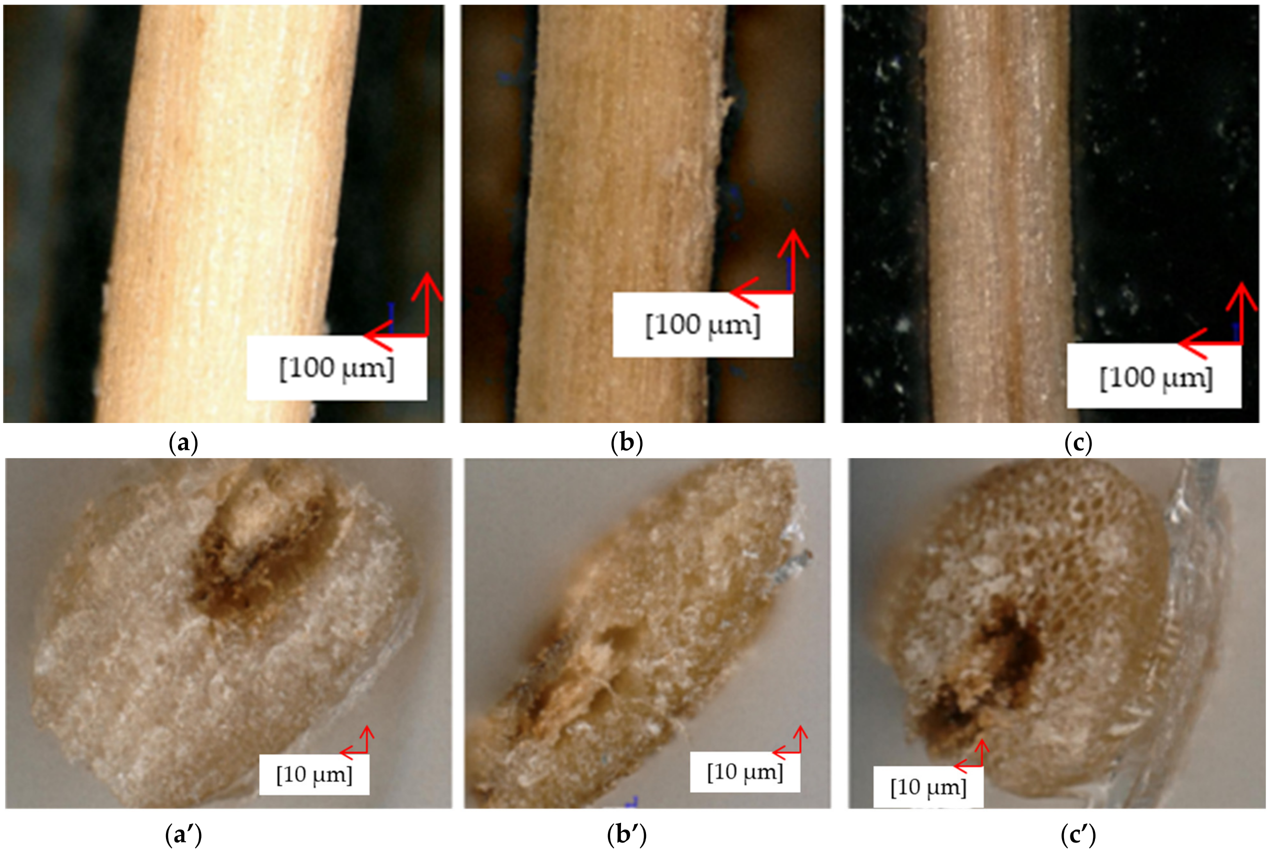


Figure 8. Digital microscopic images of surface and cross-section of coconut fibres. (**a**) and (**a′**): raw fibre; (**b**) and (**b′**): alkali-treated fibre; (**c**) and (**c′**): boiled fibre. Reprinted from [20].

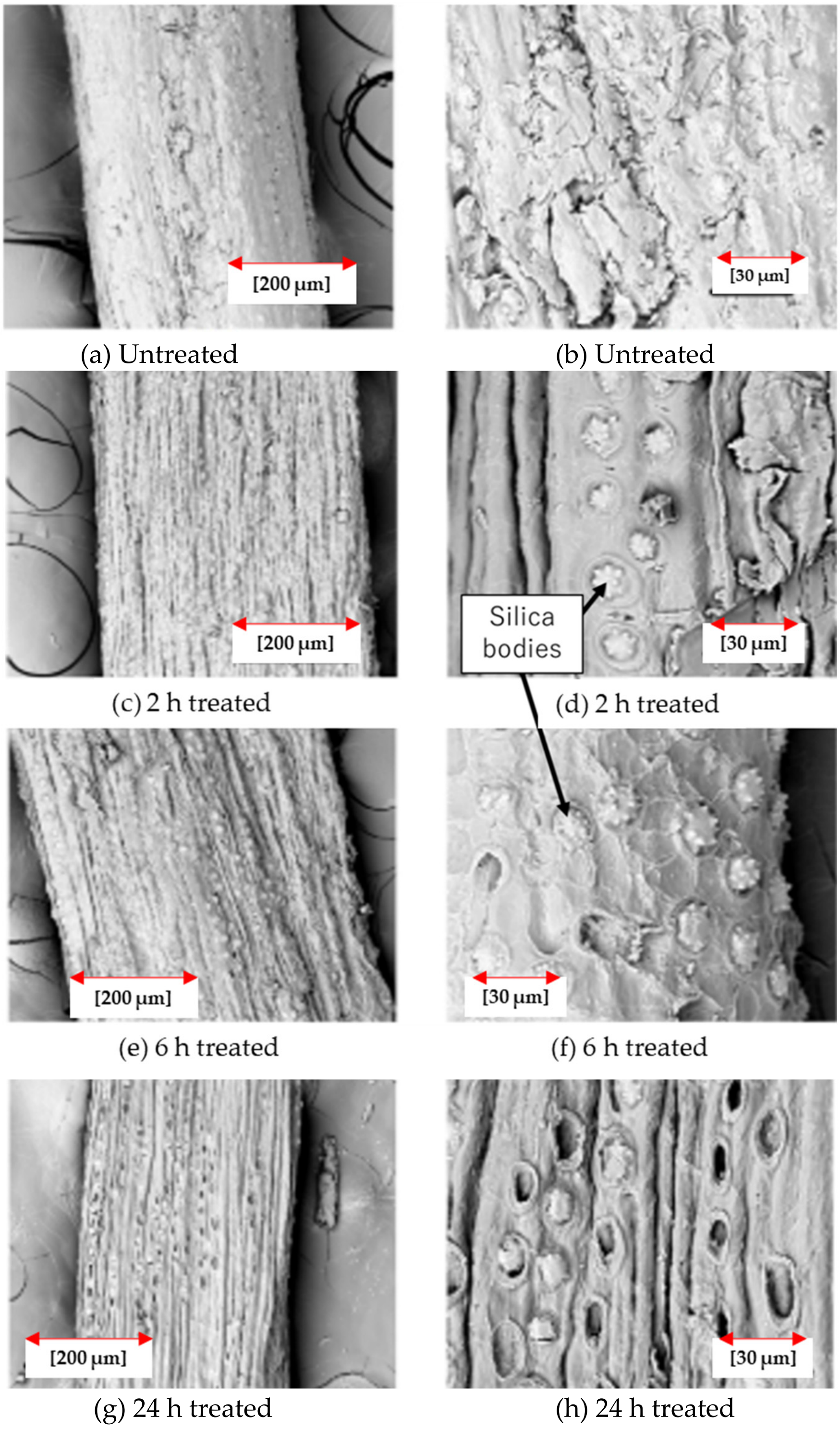


Figure 9. SEM morphologies of palm oil fibre: (**a**) untreated; (**b**) untreated; (**c**) 2 h treated; (**d**) 2 h treated; (**e**) 6 h treated; (**f**) 6 h treated; (**g**) 24 h treated; (**h**) 24 h treated. Reprinted from [23].

Momoh et al. [48] explored the physical and mechanical properties of treated palm oil fibre. They carried out three different types of pre-treatments, namely, alkaline, silane and hot water. For alkaline treatment, the fibres were soaked in 2%, 4%, 6% and 10% NaOH solution. The soaking times for each alkali solution were 30 min, 2 h, 6 h, 12 h, 24 h and 48 h. At each duration, the fibres were washed with plenty of running tap water and dried in an oven at 60 ± 3 °C for 8 h. For silane treatment, the fibres were soaked in a water and ethanol mixed solution that contained 1% and 3% triethoxyvinylsilane. The soaking times for each silane concentration were 1, 2, 4, 8, 24 and 48 h. Subsequently, the fibres were removed and washed with plenty of water from a running tap and dried in an oven at 60 °C ± 3 °C for 8 h. For hot-water treatment, the fibres were immersed in boiling water (at 100 °C) for the time durations of 15 min, 30 min, 1 h and 2 h. At the end of each duration, these fibres were rinsed with plenty of tap water and dried in an oven at 60 °C ± 3 °C for 8 h. These pre-treatment methods are shown in Table 5 and Figure 10. Figures 11 and 12 show the SEM morphologies of the surface topography and cross-section of palm oil fibres before and after treatments. A comparison between Figure 11a,b reveal that a rougher but cleaner surface topography has occurred after 48 h of 6% NaOH. In addition, the cracking and shrinkage of fibre could be indicated in Figure 12b. Figures 11c and 12c show the palm oil fibre after silane treatment. Silane treatment levelled up the undulations on the untreated fibre surface. This levelling up would be an advantage for cementitious composite adhesion between fibres and the matrix. Figures 11d and 12d show the palm oil fibre after hot-water treatment. This treatment method caused the escape of lignin molecules from the fibres and the deposition on the surface of the fibres and indicated the agglomeration of lignin on the surface of the fibre.

Table 5. Details of each pre-treatment.

Type of Pre-Treatment		
Alkaline	Percentage of solution	2%, 4%, 6% and 10% (NaOH)
	Soaking time	30 min, 2 h, 6 h, 12 h, 24 h and 48 h
Silane	Percentage of solution	1% and 3% (triethoxyvinylsilane)
	Soaking time	1 h, 2 h, 4 h, 8 h, 24 h and 48 h
Hot water	Temperature	100 °C
	Soaking time	15 min, 30 min, 1 h and 2 h

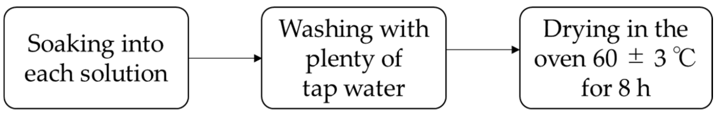


Figure 10. Flow of fibre processing. Reprinted from [48] with permission of ASCE, 2020.

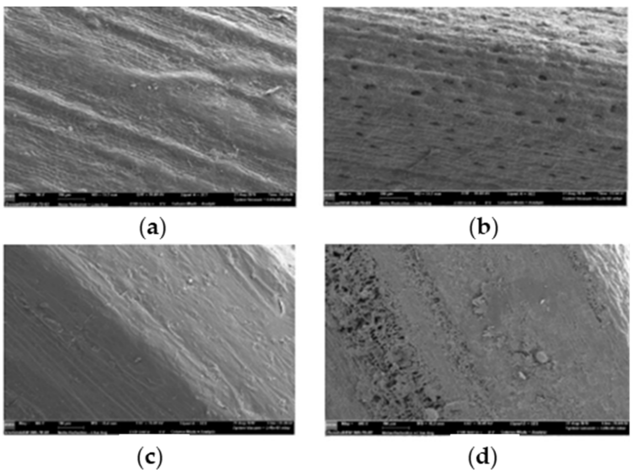


Figure 11. SEM morphologies of the surface of palm oil fibre: (**a**) untreated palm oil fibre, 100×; (**b**) alkali-treated palm oil fibre—6% NaOH at 48 h, 1000×; (**c**) silane-treated palm oil fibre—3% silane at 48 h, 100×; (**d**) hot water treatment—2 h, 1000×. Reprinted from [48] with permission of ASCE, 2020.

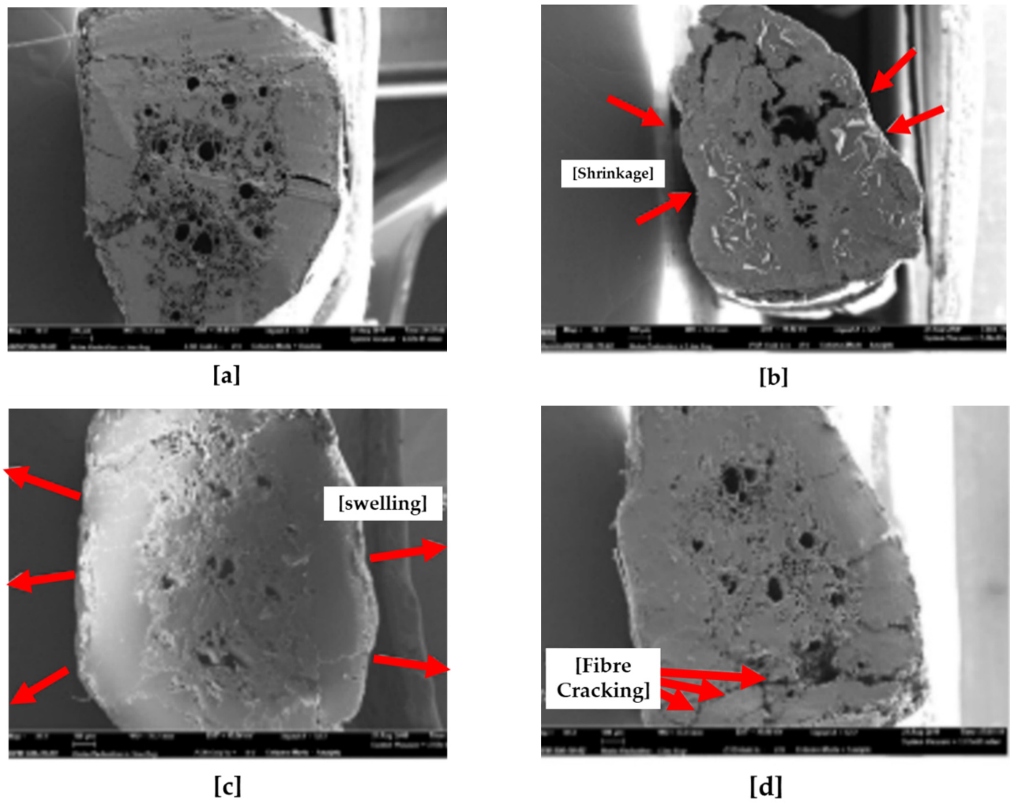
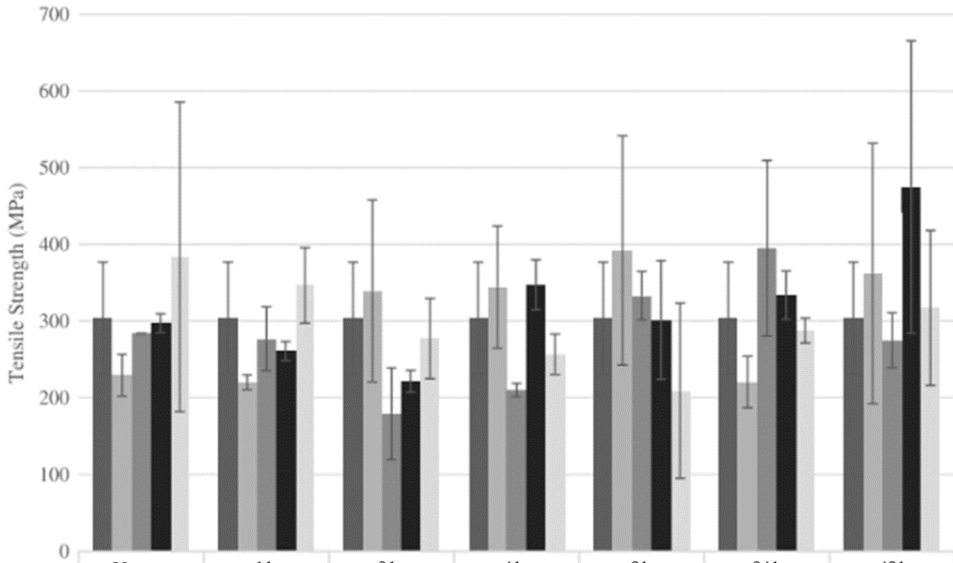


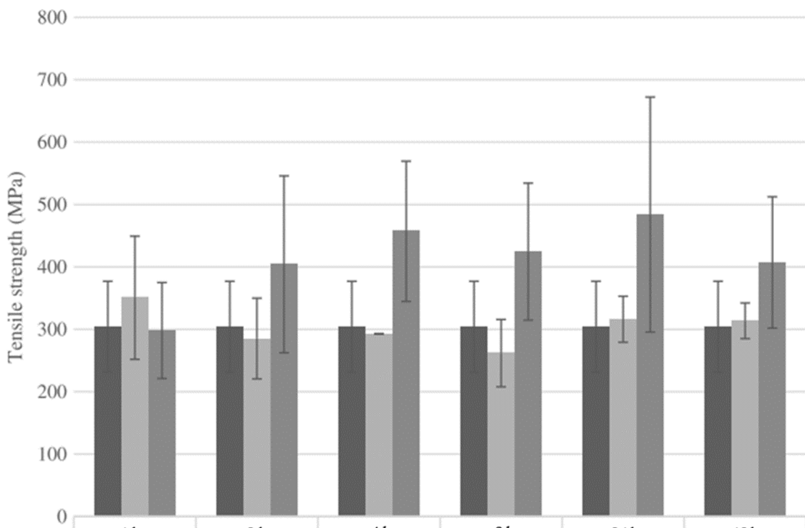
Figure 12. SEM morphologies of the cross-section of palm oil fibre: (**a**) untreated palm oil fibre, 50×; (**b**) alkali-treated palm oil fibre—6% NaOH at 48 h, 50×; (**c**) silane-treated palm oil fibre—3% silane at 48 h, 50×; (**d**) hot-water-treated palm oil fibre—2 h, 100×. Reprinted from [48] with permission of ASCE, 2020.

Figures 13–15 show the tensile strength of the different types of treatments researched by Momoh et al. [48]. In Figure 13, 6% NaOH at 48 h marked the maximum improvement in tensile strength of approximately 60%. The 2% NaOH solution indicated a more consistent improvement in tensile strength with an optimum time of 8 h. At 10% NaOH solution, tensile strength was reduced as treatment time increased. The results of tensile strength also indicated that some values for treated fibres were lower than those of the untreated fibres. In Figure 14, a remarkable improvement of 1% silane solution on the tensile strength of palm oil fibre could not be observed. However, at 3% silane solution, an improvement of the tensile strength was a maximum of 59% at 24 h. Silane treatment did not show a remarkable improvement on the tensile strength of palm oil fibre beyond 24 h, so the optimum treatment time of 24 h is recommended. Figure 15 shows that a maximum increase in the tensile strength of 66% was marked at 30 min of hot-water treatment. No improvement in the fibre tensile strength was recorded beyond 30 min. Thus, the optimum hot-water treatment time for palm oil fibre at 100 °C was recommended to be 30 min. Similar to the alkali treatment, the tensile strength results for silane and hot-water treatment methods indicated a reduction in the treated fibres at low treatment concentration and pre-treatment time.



	30 min	1 h	2 h	4 h	8 h	24 h	48 h
Untreated	304.06	304.06	304.06	304.06	304.06	304.06	304.06
2 % NaOH	229.69	220.49	339.39	344.45	392.15	220.71	362.28
4 % NaOH	284.02	277.02	179.46	210.19	333.30	395.05	275.13
6 % NaOH	297.46	261.10	221.61	347.53	301.55	333.78	475.01
10 % NaOH	383.65	346.76	277.27	256.85	209.40	287.83	317.15

Figure 13. Tensile strength of palm oil fibre subjected to NaOH treatment at various concentrations and treatment durations. Reprinted from [48] with permission of ASCE, 2020.



	1 h	2 h	4 h	8 h	24 h	48 h
Untreated	304.06	304.06	304.06	304.06	304.06	304.06
1 % Silane	350.65	285.27	292.78	261.84	316.19	313.69
3 % Silane	298.14	404.12	457.11	424.55	483.92	407.17

Figure 14. Tensile strength of palm oil fibre subjected to silane treatment at various concentrations and treatment durations. Reprinted from [48] with permission of ASCE, 2020.

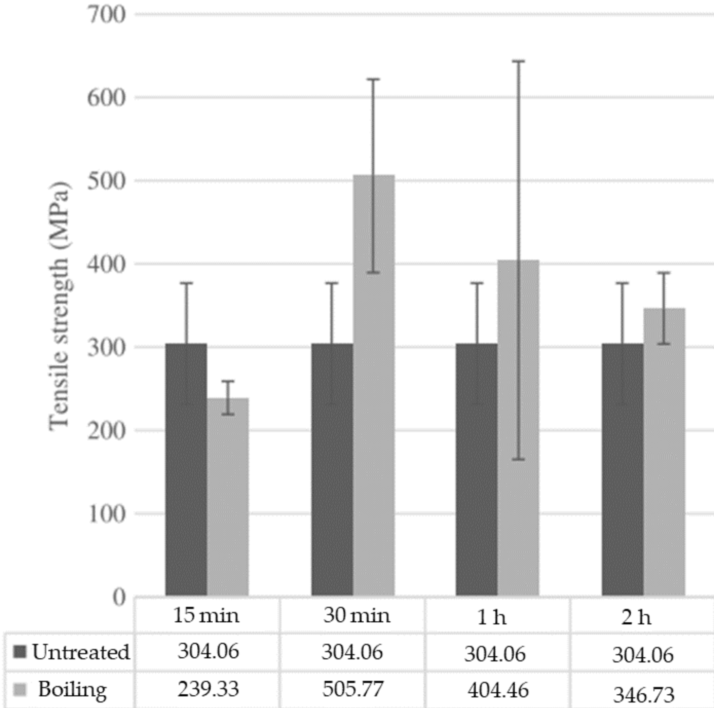


Figure 15. Tensile strength of palm oil fibre subjected to hot-water treatment for different time durations. Reprinted from [48] with permission of ASCE, 2020.

4. Mechanism of Natural Fibre as Reinforcement Material

The bridging effect is the most remarkable effect of natural fibre reinforcement for cementitious composite. Ahmad et al. [22] studied some properties of palm oil waste fibre reinforced concrete. They highlighted that this waste fibre did not have the property to improve flexural strength directly, but it can prevent the expansion of cracking by bridging the effect of palm oil fibre. That is, natural fibre can change the property of concrete from brittle to ductile. The determining factors of this effect include the tensile strength of the natural fibre and adhesion strength between the fibre and cement matrix [49]. Figure 16 shows a cracking surface of cement composite reinforced with coconut fibre. Coconut fibre worked as a bridge to keep connecting the cracking surface of the cement matrix in Figure 16a. Moreover, in Figure 16b, some holes were created by coconut fibre being pulled out. This occurrence would be a disadvantage of natural fibre reinforced composite in terms of mechanical strength. According to Momoh et al. [48], the pre-treatment of natural fibre can cover this weakness. They revealed that pre-treated natural fibre had 60% higher tensile strength and 65% higher elastic modulus than raw fibre. Furthermore, the adhesion strength was improved because the pre-treatment removed surface impurities and increased the surface area of natural fibres. In addition, Olaoye et al. [27] described that natural fibres can contain high amounts of moisture inside the matrix because of their porous structure and then release the moisture gradually. Therefore, it reduces the drying shrinkage cracking of cementitious composite caused by rapid evaporation.

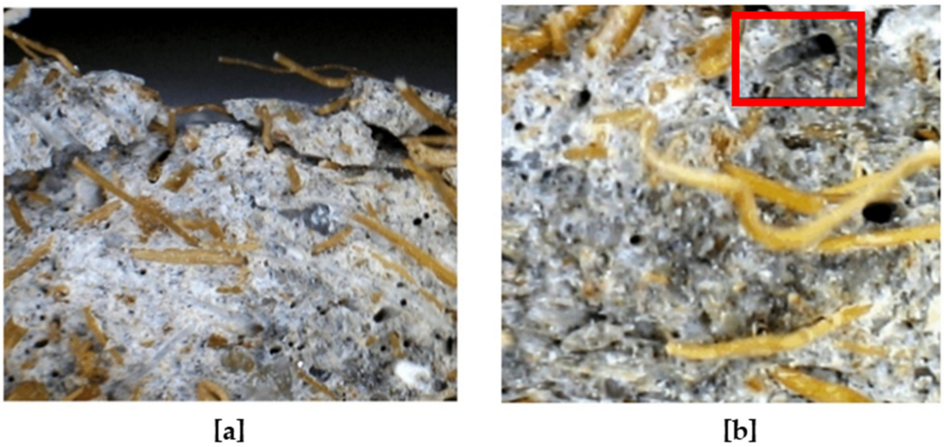


Figure 16. Crack bridging (**a**) and small holes (**b**) in the coconut fibre composite. Reprinted from [49].

5. Properties of Natural Fibre Cementitious Composite

5.1. Fresh State Properties

The slump test is widely used in construction sites all over the world to indicate the workability of concrete. This test is not a measure of workability but a measure of consistency (ACI 116R-90). This value is useful for detecting the variation in the uniformity of the nominal properties of a concrete mix. Table 6 shows the description of the workability and magnitude of a slump of normal concrete. Workability is classified into six categories from no slump (0 mm) to very high (160 to collapse) [50]. According to some previous studies, a common result is that the workability of a cementitious composite mixture decreased as the amount of natural fibre increased. This phenomenon is due to the high water absorption capacity of most types of natural fibres. When natural fibres were added to fresh mixtures, the fibres absorbed moisture inside the fresh mix. Naamandadin et al. [51] reported that the slump value of concrete with 60 mm slump value reduced to 38, 30 and 25 mm when 3%, 4% and 5% of coconut coir fibre was added to the mixture. Figure 17 shows the condition of the experiments. The higher the amount of additional fibre in the concrete mixture is, the lower the value of the workability of the concrete will be.

Table 6. Description of the workability and magnitude of a slump. Reused from [50] with permission of Elsevier, 2011.

Description of Workability	Slump (mm)
No slump	0
Very low	5–10
Low	15–30
Medium	35–75
High	80–155
Very high	160 to collapse

Abdullah [49] held the slump test of coconut fibre reinforced concrete for different percentages of 2%, 3.5% and 5% of the fibre. Their test results showed that as the percentage of natural fibre increased, the slump value dramatically decreased. The slump value of 110 mm of the normal concrete when 2%, 3.5% and 5% of the fibre was added was reduced to 40, 22 and 0 mm, respectively. Similar results were reported by Ahmad et al. [22]. They used a normal concrete mixture with a slump value of approximately 140 mm as a control mix. The concrete mixture showed good workability with a slump value of approximately 100 mm for 1% and 2% fibre contents. However, a significant and sudden reduction of up to 70% was observed in 3% fibre content concrete. The research conducted by Ahmad and Mohd Noor [44] showed that concretes that contained low volume palm oil fibres still have good workability compared with the control mix. They reported a slump value of 120, 100 and 85 mm for fibres that contain 0.25%, 0.50% and 0.75% of fibre, respectively. The slump value of a cementitious composite mixture decreased as the amount of natural fibre increased. That is, the workability of cement mixtures dramatically decreased by adding natural fibres and was undesirable to be utilised as a cementitious material, thereby becoming one of the difficulties in using natural fibres in cementitious composites. As a fresh property of natural fibre contents of cement-based material, Ozerkan et al. [24] studied the setting time of cement mortars that contain different percentages of coconut fibres. The result is shown in Table 7. As the fibre content increased, the initial and final setting times were reduced. The mixture with 2% of coconut fibre had the fastest setting time due to the water absorption capacity of the fibres. As the content of the natural fibre increased, more excessive water in the mixture was absorbed by the fibres, thereby affecting the setting times.

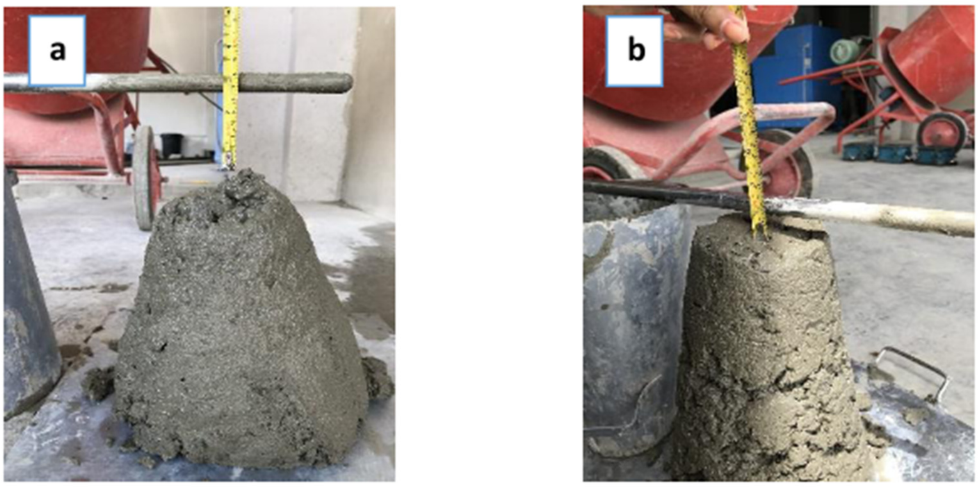


Figure 17. Slump test of concrete: (**a**) normal concrete and (**b**) coconut fibre contained concrete. Reprinted from [51].

Table 7. Setting time test results of mortar samples that contain coconut fibre. Reprinted from [24].

Fibre Content	Initial (h)	Finish (h)
0.0%	3.00	4.00
0.5%	3.15	3.55
1.0%	4.25	5.00
2.0%	2.20	2.45

5.2. Hardened Concrete Properties

5.2.1. Mechanical Properties of Coconut Fibre Reinforced Cementitious Composites

Abdullah [49] studied the effect of the inclusion of different percentages of coconut fibres on the compressive strength of cementitious composite. The specimen that contained 3% and 6% wt.% coconut fibres reduced the compressive strength to 33.73 and 38.54 MPa, respectively, while the control specimen was marked at 41.19 MPa. The specimen that contained 9% wt.% coconut fibres showed the highest compressive strength of approximately 43.84 MPa. However, the compressive strength of specimens that contain higher percentages of coconut fibre, such as 12% and 15%, was 27.05 MPa and 26.04 MPa, thereby show a significant reduction of the compressive strength of specimens with a high amount of coconut fibre. This reduction was due to the lack of water in the composites, which caused the mixtures to not have sufficient workability and therefore was difficult to mix homogeneously. If the mixture is stiff because of less water in the mixture, then the packing of the fibre at high fibre contents becomes difficult and voids will be introduced into the specimens. Figure 18 shows the compressive strength of cementitious composites that contain different percentages of short coconut fibres in different ages reported by Hwang et al. [28]. The compressive strength of specimens decreased with the increase in the coconut fibre contents at all ages. The 28-day compressive strength of the fibre that contains mixture was reduced to half compared with the control mixture when the fibre content was at a maximum of 4%. The researchers also investigated the impact resistance of concrete reinforced with short coconut fibre. Impact resistance reflects the ability of a material to absorb energy. Figure 19 shows the crack patterns of specimens after the experiment. After receiving a direct free-fall impact from a steel ball dropped, all of the samples that contained short coconut fibre remained intact, whilst the control sample broke into numerous pieces because coconut fibre distributed the impact of the steel ball strike uniformly and absorbed the impact energy.

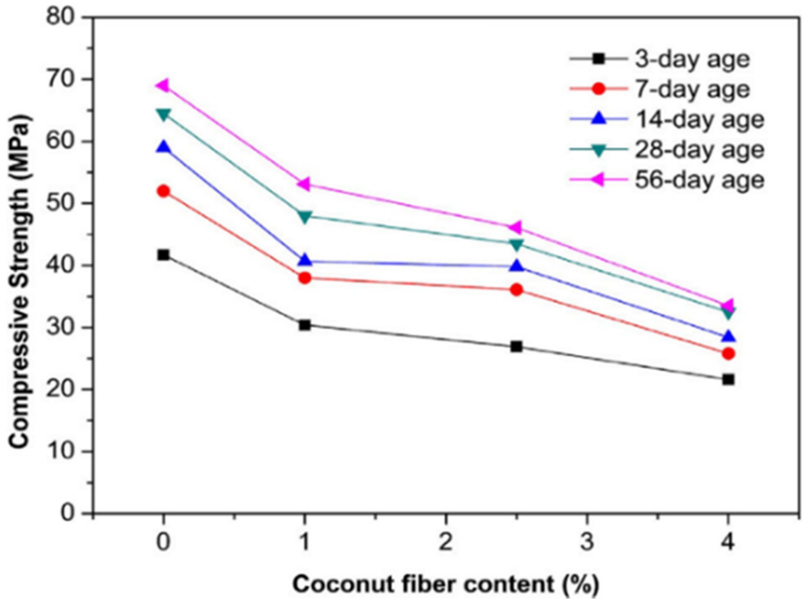


Figure 18. Compressive strength of coconut fibre cementitious composites. Reprinted from [28] with permission of Elsevier, 2016.

Naamandadin et al. [51] analysed the mechanical behaviours of concretes reinforced with coconut fibres. Table 8 shows the results of compressive and split tensile strength tests. The specimen with 3% coconut fibre had the highest compressive strength whilst the strength was reduced when the fibre content was higher than 3%. The 7 to 28 days of compressive strength ratio of mixes containing 0%, 3%, 4% and 5% of coconut fibres was 0.82, 0.81. 0.61 and 0.54, respectively. The ratios of 4% and 5% of coconut fibre-containing specimens were significantly reduced. This phenomenon may be due to the fact that these fibre contents absorbed mixing water, and no sufficient water for cement hydration at the early age of 7 days was reported. However, after 7 days, these fibres released the absorbed water into the cement matrix, which increased the cement hydration products and therefore the rate of strength gain from 7 days to 28 days was higher in these two mixes compared with control and 3% fibre content concretes. The splitting tensile strength test also showed a similar trend. Specimens with 3% of coconut fibre resulted in a splitting tensile strength of 3.56 MPa at 28 days, which was slightly higher than the control mix, whilst 5% of coconut fibre specimen resulted in 2.9 MPa, which was approximately 17% less than the control mix.

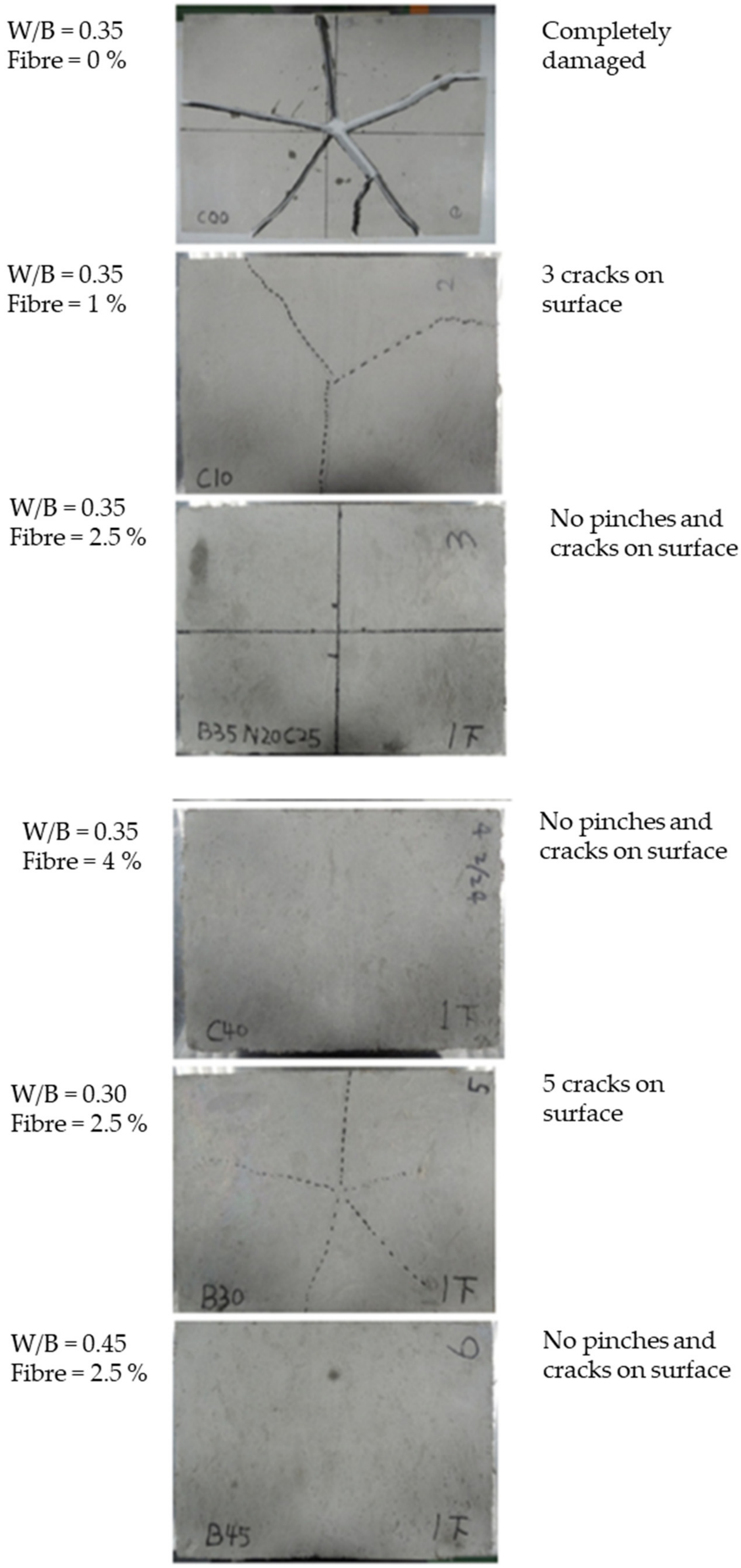


Figure 19. Crack patterns of concrete reinforced with short coconut fibre in impact resistance tests. Reprinted from [28] with permission of Elsevier, 2016.

Table 8. Results of compressive and split tensile strengths. Reprinted from [51].

Type of Strength	Materials Ages	0%	3%	4%	5%
Compressive strength (MPa)	7 days	18.23	19.53	13	8.1
	28 days	22.27	24.1	21.43	15.13
Splitting tensile Strength (MPa)	7 days	2.5	2.6	2.3	2.22
	28 days	3.48	3.56	2.95	2.9

Ramli et al. [52] studied the mechanical properties of coconut fibre reinforced concrete. According to their report, the compressive strength of the three different types of mixtures, such as normal, 0.6% and 0.8% of coconut fibre contained specimens, were 40.7, 29.8 and 27.9 MPa, respectively. Meanwhile, the result in the flexural strength of those specimens was 4.3, 3.9 and 3.8 MPa, respectively. The addition of coconut fibre reduced the mechanical strength of concrete. This reduction was more significant in compressive strength than in flexural strength. Sathiparan et al. [53] studied the properties of a coconut coir fibre-reinforced cement mortar. The higher compressive strength was obtained in the 0.5% coconut coir fibre contained specimen as 2.95 MPa, which is 5.7% higher than the control specimen. When the amount of coconut coir was increased to 0.75%, the compressive strength decreased to approximately 2.6 MPa. This phenomenon was due to the difficulty of mixing cement mortar with a higher percentage of coconut coir homogeneously. Therefore, the compaction of cement mortar became difficult and contained huge amounts of air voids in the specimens. However, the compressive strength of coconut fibre reinforced specimens were within ±6% of the control specimen. Shfafi et al. [54] conducted a compression strength test for concretes reinforced with coconut fibres with different fractions of 0%, 2%, 3.5% and 5%. According to their research, coconut fibre-containing specimens tended to show lower compressive strength at early material ages. However, the coconut fibre-containing concrete specimens had a higher growth rate of compressive strength than the normal concrete. This characteristic could be observed clearly in the concrete specimens with 5% of coconut fibre. The compressive strength was the lowest (15.23 MPa) at the age of 3 days. Then, it became 30.34 MPa, whilst the control specimen was marked 31.7 MPa at 28 days.

5.2.2. Mechanical Properties of Palm Oil Fibre Reinforced Cementitious Composites

Khoudja et al. [55] studied the compressive strength of date palm fibre (DPF) reinforced concrete. Figure 20 shows the result of compressive strength. The increase in palm oil fibre caused a decrease in compressive strength. Lertwattanaruk and Suntijitto [42] studied the compressive strength of palm oil fibre reinforced cement mortar. They also reported a similar result with Khoudja et al. [55]. A total of 15% of the palm oil fibre-contained specimen resulted in only 60% of compressive strength compared with the control specimen. Momoh and Osofero [1] studied the mechanical properties of palm oil fibre reinforced concrete. The results are shown in Figures 21–23. The same as in other studies, palm oil fibre reduced the mechanical properties. The strength of some specimens is reduced by the passage of time. They explained that this strength loss of specimens was due to the degradation of the surface of palm oil fibre in contact with the alkaline concrete matrix. These results matched with a study by Ahmad et al. [45]. They conducted the splitting tensile strength test for the concretes reinforced with different percentages of palm oil trunk fibre from 0% to 4%. The results showed that specimens with 1% fibre resulted in 2.5 MPa, whilst the result of the control specimen was improved to 1.6 MPa. However, beyond this percentage, the strength gradually decreased, and 4% of the fibre-containing specimen, which was weaker than the control specimen, was marked 1.5 MPa.

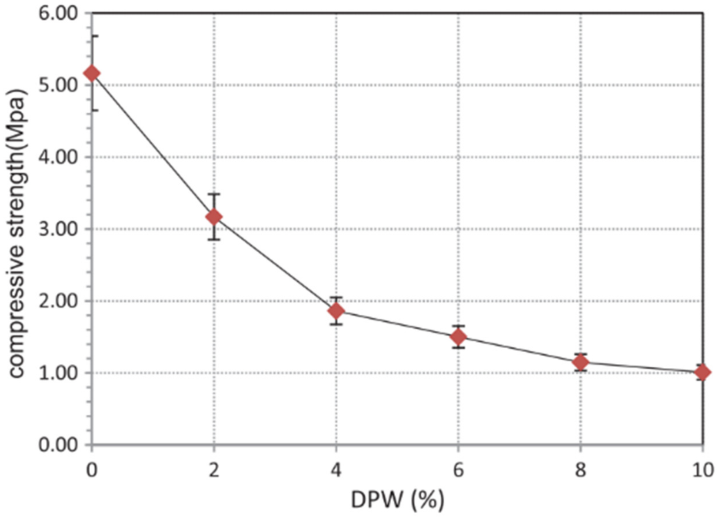


Figure 20. Compressive strength test of DPF reinforced concrete. Reprinted from [55] with permission of Elsevier, 2021.

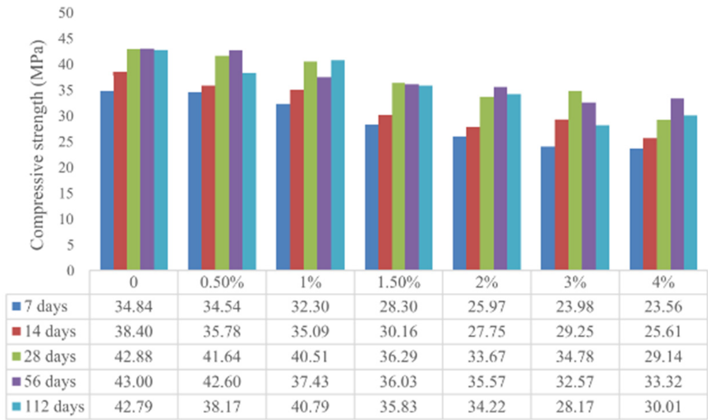


Figure 21. Compressive strength test results of palm oil fibre concrete at different ages. Reprinted from [1] with permission of Elsevier, 2019.

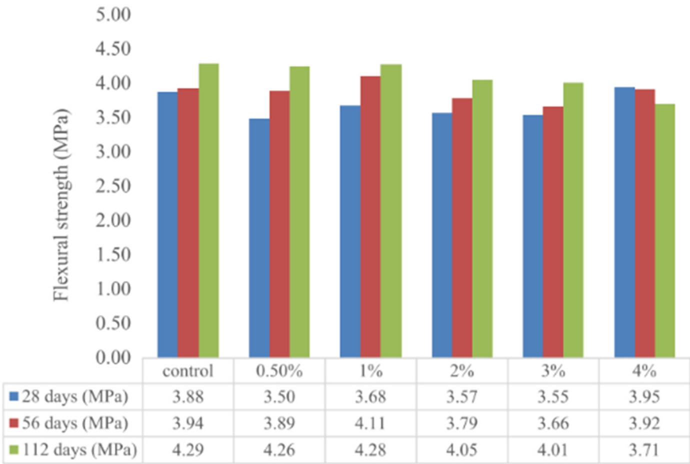


Figure 22. Flexural strength test results of palm oil fibre concrete at different ages. Reprinted from [1] with permission of Elsevier, 2019.

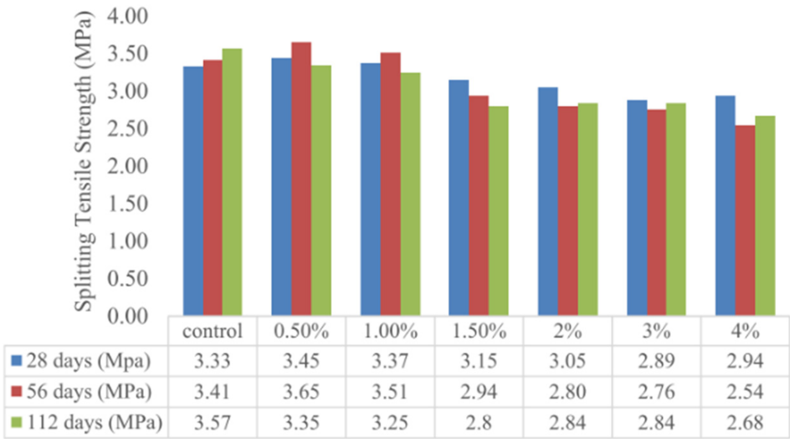


Figure 23. Splitting tensile strength test results of palm oil fibre concrete at different ages. Reprinted from [1] with permission of Elsevier, 2019.

Although some studies concluded that natural fibre caused the strength reduction of cement composite, Lee et al. [56] reported that palm oil fibre improved the mechanical properties. The test results of the compressive strength are shown in Figure 24. C0, O5, O10 and O15 refer to the control specimen, specimens containing 5 kg/m^3 of palm oil fibre, specimens containing 10 kg/m^3 and specimens containing 15 kg/m^3, respectively. As the amount of palm oil fibre increased, the compressive strength improved. They justified that the inclusion of palm oil fibre in concrete helped to inbound the concrete matrix in a lateral direction, thereby increasing the confinement effect and indirectly improving the strength of concrete when the palm oil fibre was compressed. Ramli and Dawood [57] studied the effects of palm fibre on the mechanical properties of lightweight concrete. Figures 25 and 26 show the test results of compressive and flexural strengths. According to their research, strength was increased until the fibre content was 0.8%. Beyond this percentage, strength was decreased.

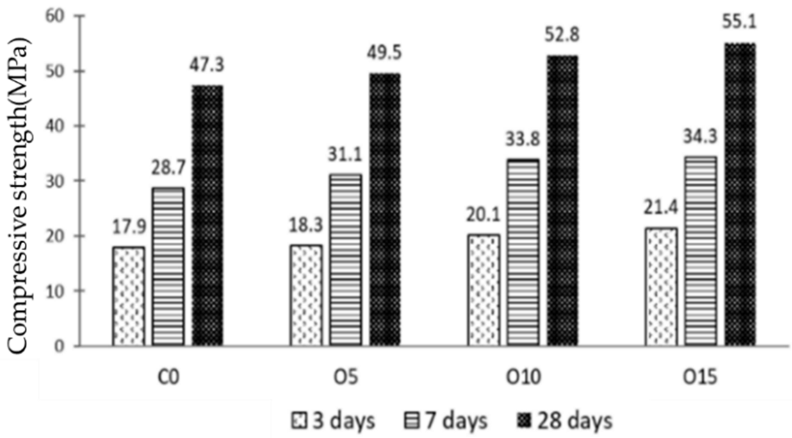


Figure 24. Compressive strength of palm oil fibre concrete at different ages. Reprinted from [56].

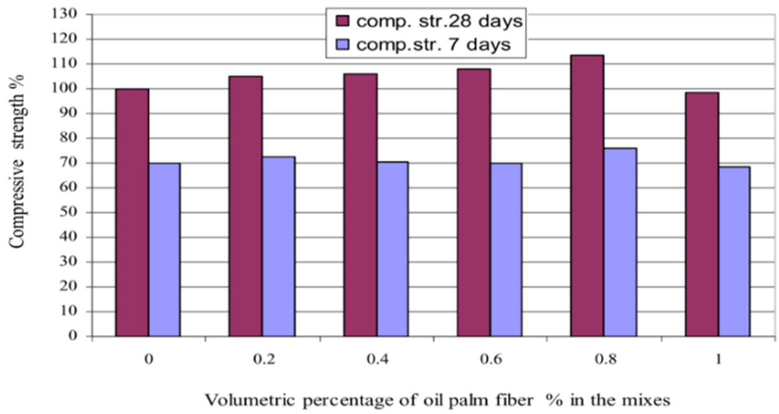


Figure 25. Relationship between palm fibre content and compressive strength in lightweight concrete. Reprinted from [57].

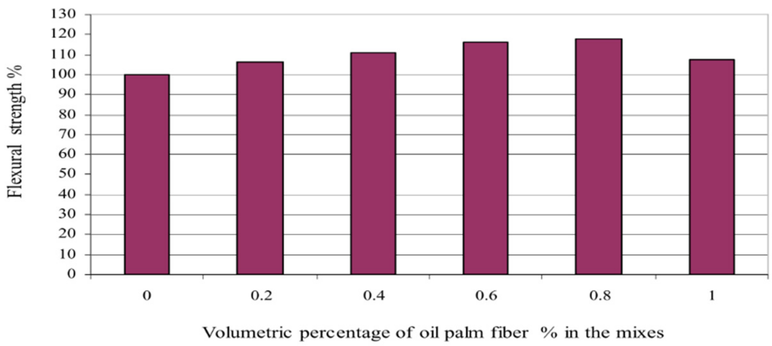


Figure 26. Relationship between palm fibre content and flexural strength in lightweight concrete. Reprinted from [57].

Ozerkan et al. [24] studied the compressive and tensile performance of palm oil fibre reinforced cement mortar for the specimens that contain up to 2% of palm oil fibres. The results are shown in Figure 27. The compressive strength of the samples with 0.5% fibre content was higher than the control sample at an early age but it was similar at 28 days. However, beyond this percentage, the compressive strength decreased. They assumed that the high compaction between the fibres and the cement matrix was likely achieved and led to the good homogeneity in a mix with 0.5% fibre content. However, in Figure 28, the split tensile strength was lower than the control mix at the early and later ages for all specimens that contain palm oil fibre.

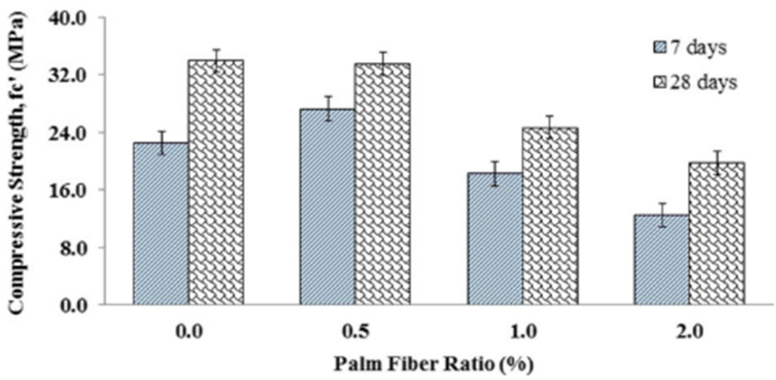


Figure 27. Effect of palm oil fibre contents on the compressive strength of cement mortar. Reprinted from [24].

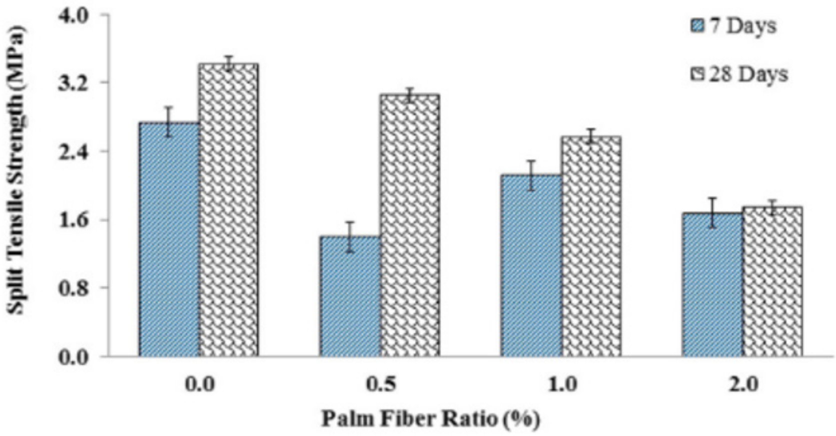


Figure 28. Effect of palm oil fibre contents on the splitting tensile strength of cement mortar. Reprinted from [24].

Abdullah et al. [46] studied the compressive strength of palm oil trunk fibre in cement composite that contained up to 6% fibres. The compressive strength at 28 days was significantly increased for specimens that contained 2% of palm oil trunk fibre that resulted in 38.61 MPa, whilst the control specimen was 15.15 MPa. Beyond this percentage, the compressive strength was gradually decreased. Specimens that contain 6% of coconut fibre, which had a maximum amount of fibre, was marked as 16.02 MPa, and it was slightly higher than the control specimen. The authors described that a small amount of fibre content could be dispersed well in cement composite and thus increase the packing density of cement composite, thereby increasing the compressive strength. Dawood and Ramli [43] reported that the increase in the mechanical properties of cement mortar was due to the inclusion of palm oil fibre in certain percentages. Figures 29 and 30 present the test results of the compressive and flexural strengths, respectively. These mechanical properties were improved by the inclusion of palm oil fibre at up to 0.6%, whilst beyond that, the strengths were dropped. The authors described that the strength reduction was due to the excessive natural fibre that contained high amounts of air voids inside the matrix when it was mixed.

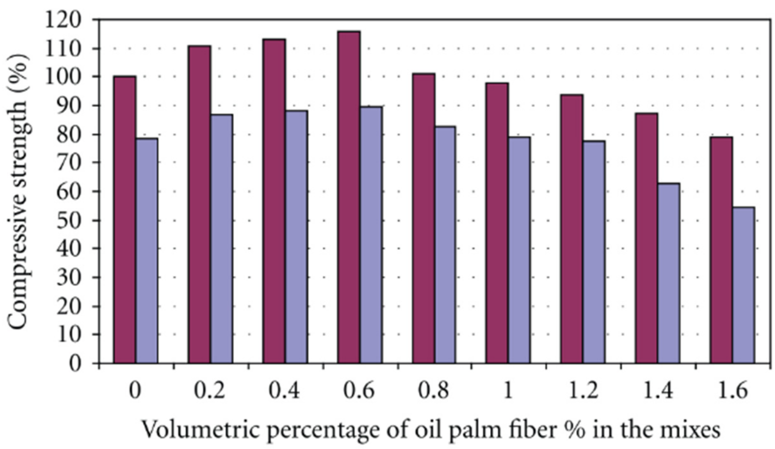


Figure 29. Relationship between the natural fibre content and compressive strength. Reprinted from [43] (red bars are 28 days and blue bars are 7 days).

Ferdiansyah and Razak [25] studied the mechanical properties of black sugar palm fibre-reinforced concrete. According to their report, the compressive strength at 28 days for the control was 53.6 MPa. The highest compressive strength at 28 days for a mix with 0.2% fibre with fibre length of 35 mm was 60.7 MPa compared with the control, which is an increase of 13%. The lowest compressive strength at 28 days was 46 MPa for a mix with 0.8% fibre with a fibre length of 35 mm and a reduction of 7% compared with the control. The increase in strength has occurred for the mix with 25 mm fibre length, but the mixes with 15 and 35 mm fibre lengths showed a decrease in compressive strength. This phenomenon was due to the clustering of the fibres, thereby making it difficult to have a random distribution of fibres in the wet mix. This phenomenon is called the balling effect. Figure 31 shows the flexural strength test results of concrete reinforced with 0.8% of the fibre with different lengths. The inclusion of fibres in the concrete mixture did not affect the flexural strength at an early age (7 days). However, the strength was higher than in the plain concrete at later ages. The highest flexural strength was 6.0 MPa for 0.8% fibre with a fibre length of 35 mm, whilst the control specimens were 5.6 MPa with an increment of approximately 9%. They highlighted that a large number of fibres improved the bonding inside the matrix and also attributed to the fact that the fibres avoided the expansion of microcracks. They also studied the development of flexural strength with ages. This figure shows that generally, the fibre content had a positive effect on the flexural strength. However, a mix with 35 mm length fibre showed a small reduction in strength after 56 days. The reason is that natural fibre may have been the cause of the structural deterioration of lignin. Lignin is responsible for the stiffness of the plant.

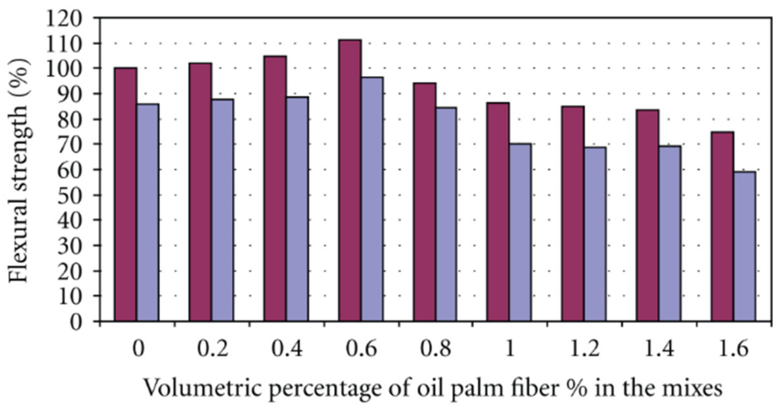


Figure 30. Relationship between the natural fibre content and flexural strength Reprinted from [43] (red bars are 28 days and blue bars are 7 days).

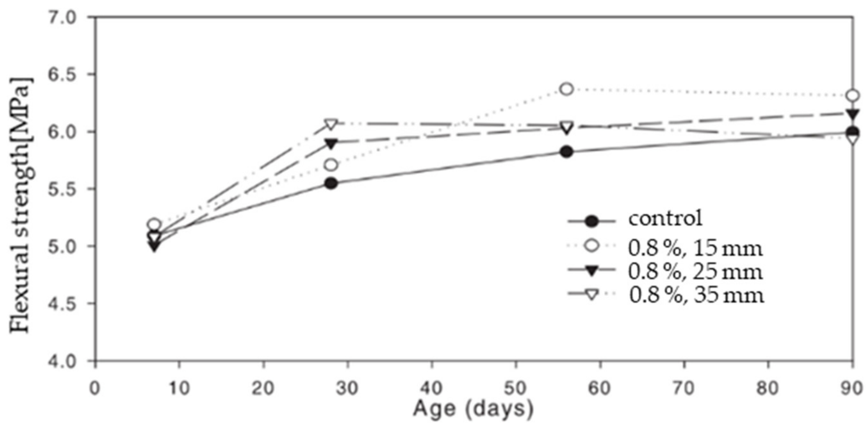


Figure 31. Development of flexural strength with age for 0.8% fibre mix. Reprinted from [25].

Benmansour et al. [58] investigated the compressive strength of cement mortar reinforced with DPF. The DPFs were separated into two by their size (Figure 32) and made three different fibre types, namely, DPF6, DPF3 and DPF6+DPF3 mix. They tested the compressive strength of 0%, 5%, 10% and 15% of fibre-containing specimens for each fibre type. The result shows that the compressive strength was dramatically decreased with the increase in DPF content. For specimens that contain 5% of DPF, the compressive strength was decreased by approximately 91.90% for MDP6, 92% for MDP3 and 85% for

DPF6+DPF3 mixes compared with the control specimen. They explained that the increase in the porosity of the composite material as a result of fibre addition is the major factor responsible for the reduction of compressive strength.

Figure 32. DPF in different sizes: DPF_6 and DPF_3. Reprinted from [58] with permission of Elsevier, 2014.

Ahmad et al. [22] investigated the mechanical properties of palm oil fibre reinforced concrete. The compression strength results are shown in Table 9. The compressive strength was highest at 1% fibre content. However, beyond this percentage, strength decreased. This effect could be seen in flexural and split tensile strength. Ahmad and Mohd Noor [44] researched palm oil fibre concrete reinforced concrete-containing pulverised fly ash (PFA). They mixed 0.25% to 0.75% of palm oil fibre into concrete. The compressive strength is shown in Figure 33. The vertical axis illustrates the compressive strength, and the horizontal axis shows the percentage of palm oil fibre. Compressive strength decreased as the amount of fibre increased. The 0.25% fibre specimen of 0% PFA-containing specimens was 43 N/mm^2, which was the highest compressive strength, and the 0.75% specimen was 37 N/mm^2, which was the lowest strength. Palm oil fibre also had a positive effect on tensile splitting strength (Figure 34). The tensile splitting strength was increased as the amount of palm oil fibre increased. The strengths of 0.25% and 0.75% specimens of 0% PFA-containing specimens were 4.1 and 4.8 N/mm^2, respectively. They explained that it was due to the increase in the toughness of concrete provided by the existence of palm oil fibres.

Table 9. Mechanical properties of concrete with various volume percentages of OPF. Reprinted from [22].

Volume of Fibre%	Compressive Strength (MPa)	Flexural Strength (MPa)	Split Tensile Strength (MPa)
0	30.5	27.2	1.6
1	39.6	32.2	2.0
2	27.3	22.3	1.5
3	22.3	23.8	1.7

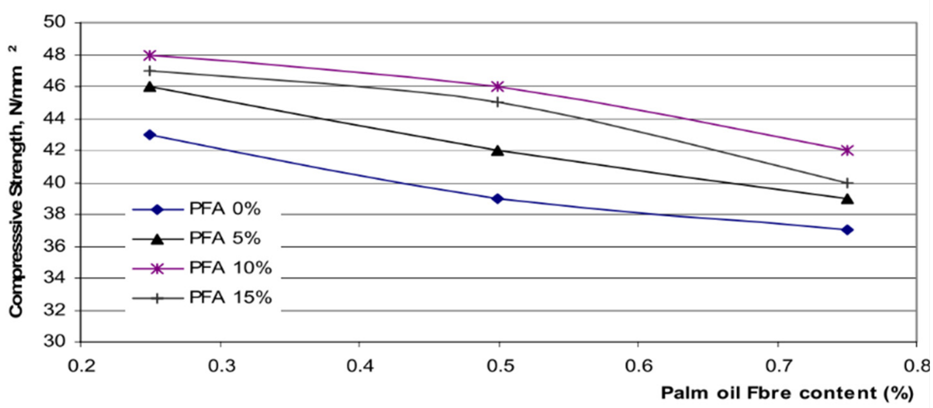


Figure 33. Compressive strength of palm oil fibre reinforced concrete. Reused from [44].

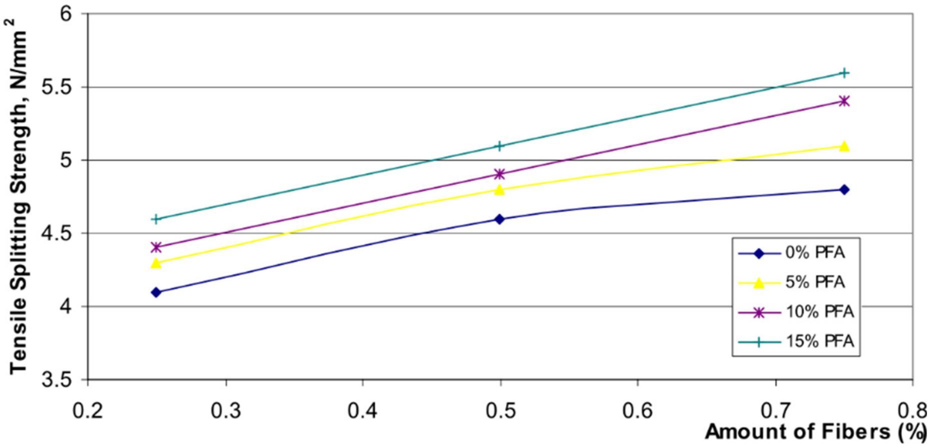


Figure 34. Tensile splitting strength of palm oil fibre reinforced concrete. Reused from [44].

Tables 10 and 11 are the summaries of the above results. Conflicting reports about the influence of natural fibres on the mechanical properties of cement-based materials have been published. Some researchers reported that natural fibre adversely affects the mechanical properties; however, other reports show that the inclusion of these natural fibres improved (in some reports, significant improvement was reported) the mechanical properties. According to the ACI 318 (chapter 5), the specified compressive strength of concrete at the age of 28 days shall not be less than 2500 psi (17.2 MPa). This standard was compared with the data of this review paper. The test results reported from Abdullah [49] indicated that the maximum and minimum 28-day compressive strength was 43.84 MPa and 26.04 by adding 9% and 15% of coconut fibre, respectively. Momoh and Osofero [1] reported that the maximum compressive strength of palm oil fibre was 41.64 MPa (by adding 0.50% fibre), and the minimum compressive strength was 29.14 MPa (by adding 4% fibre). Coconut and palm oil fibre reinforced composites had acceptable compressive strength. In addition, the test results of the tensile strength showed a similar trend with the compressive strength. The addition of excessive natural fibres into the cement-based materials decreases the mechanical properties. However, generally, research reports show that an appropriate amount of natural fibres has a positive effect on the mechanical properties of cementitious composites. Therefore, the optimum dosage depends on the mixed proportions of the cementitious matrix and the condition of the natural fibre.

Table 10. Mechanical properties of coconut fibre reinforced cementitious materials at 28 days.

Reference	Mechanical Properties (MPa)	Coconut Fibre Content (%)														
		0	**0.5**	**0.6**	**0.75**	**0.8**	**1.0**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**	**6.0**	**9.0**	**12**	**15**
[49]	Compressive strength	41.19	-	-	-	-	-	-	-	33.73	-	-	38.54	43.84	27.05	26.04
[28]	Compressive strength	65	-	-	-	-	50	-	45	-	35	-	-	-	-	-
[51]	Compressive strength	22.7	-	-	-	-	-	-	-	24.1	21.43	15.13	-	-	-	-
	Split tensile strength	3.48	-	-	-	-	-	-	-	3.56	2.95	2.9	-	-	-	-
[52]	Compressive strength	40.7	-	29.8	-	27.9	-	-	-	-	-	-	-	-	-	-
	Flexural strength	4.3	-	3.9	-	3.8	-	-	-	-	-	-	-	-	-	-
[53]	Compressive strength	-	2.95	-	2.6	-	-	-	-	-	-	-	-	-	-	-
[54]	Compressive strength	31.7	-	-	-	-	-	39.05	-	38.3	-	30.34	-	-	-	-

Table 11. Mechanical properties of palm oil fibre reinforced cementitious materials at 28 days.

Reference	Mechanical Properties (MPa)	Palm Oil Fibre Content (%)																				
		0	0.2	0.25	0.4	0.5	0.6	0.75	0.8	1.0	1.2	1.4	1.5	1.6	2.0	3.0	4.0	5.0	6.0	8.0	10	15
[55]	Compressive strength	5.2	-	-	-	-	-	-	-	-	-	-	-	-	3.2	-	1.8	-	1.6	1.2	1.0	-
[42]	Compressive strength	46.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36.9	-	-	34.7	28.3
[1]	Compressive strength	42.9	-	-	-	41.6	-	-	-	40.5	-	-	-	-	33.7	34.8	29.1	-	-	-	-	-
	Flexural strength	3.88	-	-	-	3.5	-	-	-	3.68	-	-	-	-	3.57	3.55	3.95	-	-	-	-	-
	Split tensile strength	3.33	-	-	-	3.45	-	-	-	3.37	-	-	3.15	-	3.05	2.89	2.94	-	-	-	-	-
[45]	Split tensile strength	1.6	-	-	-	-	-	-	-	2.5	-	-	-	-	1.5	1.8	1.5	-	-	-	-	-
[56]	Compressive strength	47.3	49.5 (5 kg/m^3 of fibre)	-	52.8 (10 kg/m^3 of fibre)	-	55.1 (15 kg/m^3 of fibre)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[57]	Compressive strength	23	24.15	-	24.38	-	24.84	-	25.76	22.77	-	-	-	-	-	-	-	-	-	-	-	-
	Flexural strength	4.15	4.39	-	4.6	-	4.8	-	4.93	4.52	-	-	-	-	-		-	-	-	-	–	
[24]	Compressive strength	32.2	-	-	-	32.1	-	-	-	24.0	-	-	-	-	16.4	-	-	-	-	-	-	-
	Split tensile	3.4	-	-	-	3.1	-	-	-	2.4	-	-	-	-	1.6	-	-	-	-	-	-	-
[46]	Compressive strength	15.15	-	-	-	-	-	-	-	-	-	-	-	-	38.6	-	-	-	16.02	-	-	-
[43]	Compressive strength	53	58.3	-	59.36	-	60.95	-	53.53	51.94	49.29	46.64	-	42.4	-	-	-	-	-	-	-	-

Table 11. *Cont.*

Reference	Mechanical Properties (MPa)	Palm Oil Fibre Content (%)																				
		0	**0.2**	**0.25**	**0.4**	**0.5**	**0.6**	**0.75**	**0.8**	**1.0**	**1.2**	**1.4**	**1.5**	**1.6**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**8.0**	**10**	**15**
	Flexural strength	7.6	7.75	-	7.98	-	8.43	-	7.14	6.68	6.46	6.23	-	5.7	-	-	-	-	-	-	-	-
[25]	Compressive strength	53.6	57.4 (15 mm) 56.1 (25 mm) 60.7 (35 mm)	-	54.7 (15 mm) 53.6 (25 mm) 46.7 (35 mm)	-	51.4 (15 mm) 60.6 (25 mm) 54.1 (35 mm)	-	48.0 (15 mm) 55.2 (25 mm) 46.1 (35 mm)	-	-	-	-	-	-	-	-	-	-	-	-	-
	Flexural strength	5.55	6.074 (15 mm) 5.62 (25 mm) 5.60 (35 mm)	-	5.48 (15 mm) 5.63 (25 mm) 5.92 (35 mm)	-	5.81 (15 mm) 5.55 (25 mm) 5.8 (35 mm)	-	5.71 (15 mm) 5.9 (25 mm) 6.07 (35 mm)	-	-	-	-	-	-	-	-	-	-	-	-	-
[58]	Compressive strength	34.9	-	-	-	-	-	-	-	-	-	–		-	-	-	-	32.07 (MDP6) 32.1 (MDP3) 29.6 (MIX)	-	-	-	-
[22]	Compressive strength	30.5	-	-	-	-	-	-	-	39.6	-	-	-	-	27.3	22.3	-	-	-	-	-	-
	Flexural	27.2	-	-	-	-	-	-	-	32.2	-	-	-	-	22.3	23.8	-	-	-	-	-	-
	Split tensile strength	1.6	-	-	-	-	-	-	-	2.0	-	-	-	-	1.5	1.7	-	-	-	-	-	-
[44]	Compressive strength	-	-	43	-	39	-	37	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Split tensile strength	-	-	4.1	-	4.6	-	4.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-

5.2.3. Durability Properties of Natural Fibre Reinforced Cementitious Composites

Abdullah et al. [46] investigated the durability properties of concrete reinforced with different amounts of palm oil fibre. According to their research, the density test results showed that the inclusion of this natural fibre reduced the density of concrete. The reduction of 7.2%, 8.9% and 11.3% resulted from the inclusion of 2%, 4% and 6% palm oil fibre compared with a normal weight concrete. Furthermore, water absorption was increased with fibre content. The authors explained that the increment in fibre content will increase the impurities, void volume and water absorption. These results matched with a study by Hwang et al. [28]. In Figure 35, the water absorption of specimens with 1%, 2.5%, and 4% volume fractions of coconut fibre was 7.1%, 7.5%, and 8% at 24 h, respectively, whilst the control specimen was 6.2%. The authors described that this result may be due to the high water absorption of coconut fibre, which is attributable to the increase in voids in the binder matrix. In addition, a higher amount of coconut fibre content led to the blocking and clustering of fibres, which generated capillary pores in the matrix caused by decreasing consistency. Figure 36 shows the porous structure of a fibre–cement interface.

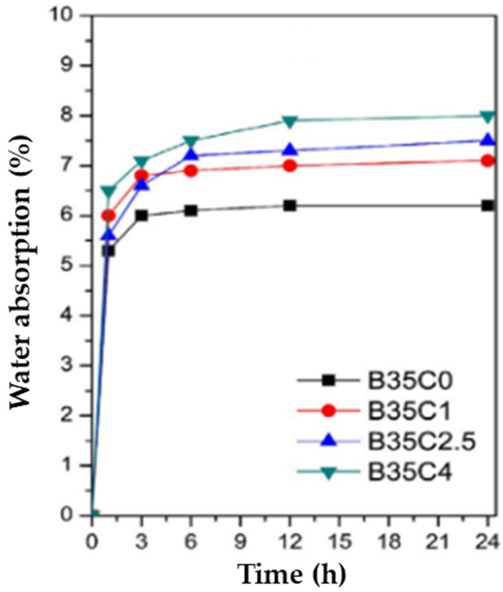


Figure 35. Water absorption vs. coconut fibre volume fraction. Reprinted from [28] with permission of Elsevier, 2016.

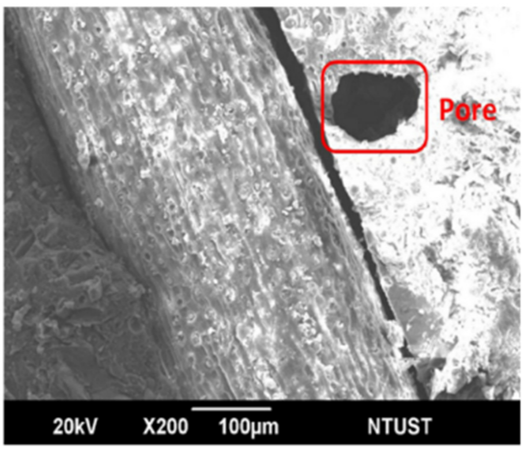


Figure 36. SEM morphologies of the fibre–matrix interface. Reprinted from [28] with permission of Elsevier, 2016.

Ozerkan et al. [24] studied the drying shrinkage behaviour of coconut fibre reinforced mortar. Figure 37 shows the effect of the palm oil fibre ratio on drying shrinkage. Mix1 is the control mix; and Mix 2, Mix 3 and Mix 4 are the mixtures with 0.5%, 1.0% and 2.0% fibre contents, respectively. The rate of increasing drying shrinkage for Mix 2 and Mix 3 was high at the age of 11 days because of the curing process. After 11 days, palm fibres affect the reduction of drying shrinkage. The mortars reinforced with 2.0% palm fibre, which is the maximum ratio tested in this research, has the least drying shrinkage. This result agrees with a study by Ahmad et al. [45]. They studied the drying shrinkage of concrete reinforced with different fractions of palm oil fibre. Figure 38 shows that palm oil fibre reinforced concretes showed less drying shrinkage than control specimens. A total of 4% palm oil fibre, which was the maximum fibre amount of this experiment reinforced concrete, had the least drying shrinkage. Hence, palm oil fibre can prevent the expansion of cracks. This result matched with that of Olaoye et al. [27]. They reported that natural fibres can contain high amounts of moisture inside the matrix because of their porous structure and then release the moisture gradually. Drying shrinkage is one of the most dangerous issues that lead to the deterioration of cementitious composites [59]. The results proving that the property of natural fibre contributing to reducing the drying shrinkage of concrete would be key in the future research of this area.

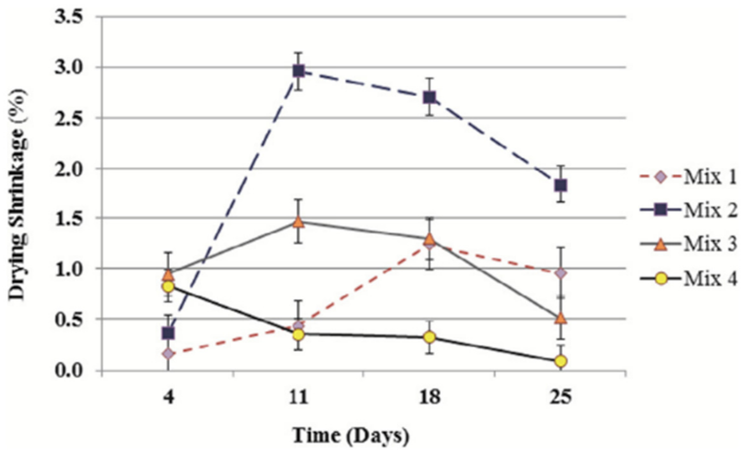


Figure 37. Effect of the palm oil fibre ratio on the drying shrinkage of cement mortar. Reprinted from [24].

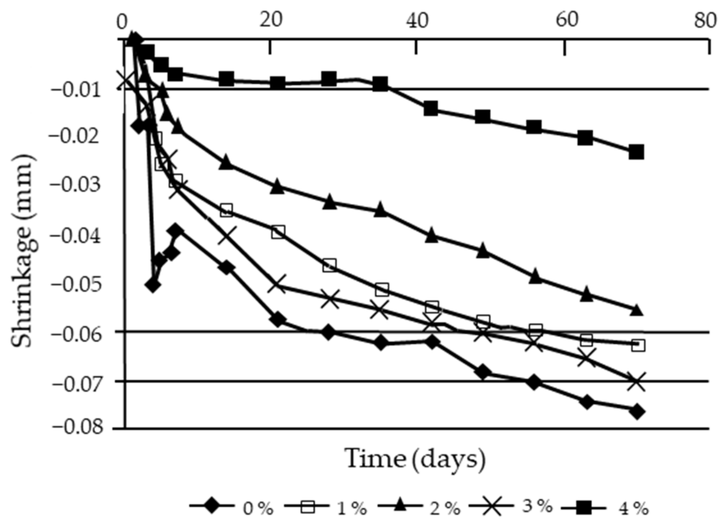


Figure 38. Effect of volume of palm oil fibre on drying shrinkage. Reprinted from [45].

5.2.4. Thermal Properties Natural Fibre Reinforced Cementitious Composites

Good building materials can resist heat transfer in terms of thermal properties, that is, they can keep the room temperature stable and reduce the energy of the air-conditioning system. As a feature of the good thermal properties of building materials, those materials have low thermal conductivity and diffusivity and high specific heat. Lertwattanaruk and Suntijitto [42] studied the thermal conductivity property of coconut coir and palm oil fibre reinforced cementitious composites. The results are shown in Figure 39. OPC is the control specimen; C5, C10 and C15 are the coconut fibre reinforced specimens; and P5, P10 and P15 are the palm oil fibre reinforced specimens. Thermal conductivity was significantly reduced (40–60%) irrespective of the type of fibre. However, the palm oil fibre reinforced specimens showed better results in thermal conductivity reduction than the coconut fibre. The authors described that increasing the porosity inside the mixture leads to lower bulk density (Figure 40). Thus, the bulk density and thermal insulation are in proportion. This conclusion is matched with the explanation of Suhaili et al. [60]. They described that incorporating air voids into the concrete mixture enhances the thermal properties. They also reported in their research that density is mostly related to the thermal conductivity of concrete.

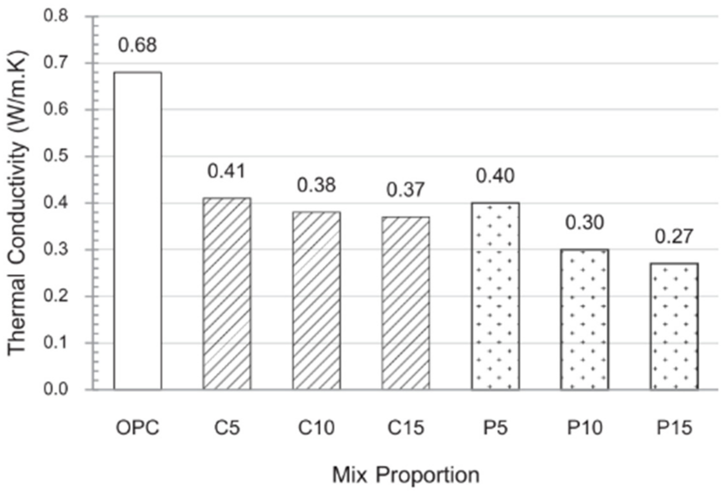


Figure 39. Thermal conductivity of coconut (C) and palm oil (P) fibre cement mortars in comparison with OPC plain mortar. Reused from [42] with permission of Elsevier, 2015.

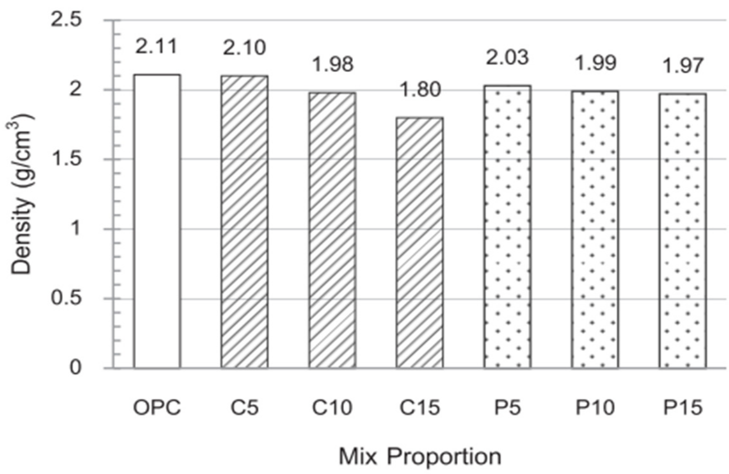


Figure 40. Density of coconut (C) and palm oil (P) fibre cement mortars in comparison with OPC plain mortar. Reused from [42] with permission of Elsevier, 2015.

Rachedi and Kriker [30] researched the thermal properties of plaster reinforced with DPFs. The thermal conductivity of 2% of DPF added to cementitious composite was improved by approximately 50% compared with the control specimens (Figure 41). They also investigated thermal diffusivity and specific feat. The results are shown in

Figures 42 and 43. The natural fibre contents increase with specific heat. That is, increasing the DPF contents provides more composite capacity to absorb heat, and this feature enables the composites to be reinforced with fibres in a more insulative way than the control composite. In terms of thermal diffusivity, the results indicated that the addition of palm fibres to composites permits the reduction of thermal diffusivity. Thus, the transfer of heat flow takes more time to cross the composite in comparison with control specimens. Two explanations are provided to explain this phenomenon. The first is related to the insulating properties of palm fibres. The thermal properties of a composite depend on the inclusions that constitute it. The lower the thermal conductivity of the inclusions, the higher the insulation of the composite. The second refers to the addition of natural fibres, which lead to an increase in the pores inside the cement matrix and decrease in the density of the composite and, consequently, its thermal properties. Awang and Ahmad [61] researched the thermal properties of the specimens, in which 0.25% and 0.40% of palm oil fibres were added to foamed concrete. According to the results, palm oil fibre did not have a significant effect in improving thermal properties. In terms of thermal conductivity, 0.25% and 0.40% palm fibre reinforced specimens were 0.42 and 0.41 w/m k, respectively, while the control specimen was 0.42 w/mk. Regarding thermal diffusivity, the control specimen and 0.25% and 0.4% palm oil fibre-containing specimens were 0.6, 0.5 and 0.45 mm^2/s, respectively. Specific heat was 0.7, 0.8 and 0.9 M/m^3K. From those literature reviews, at least 0.5% of natural fibre is needed to improve the thermal properties of cementitious materials.

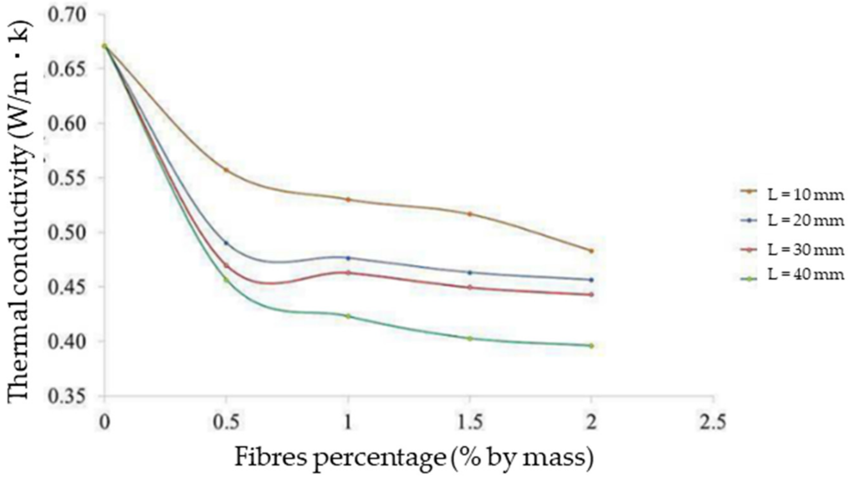


Figure 41. Thermal conductivity of the composites as a function of the percentage and length of DPFs. Reprinted from [30].

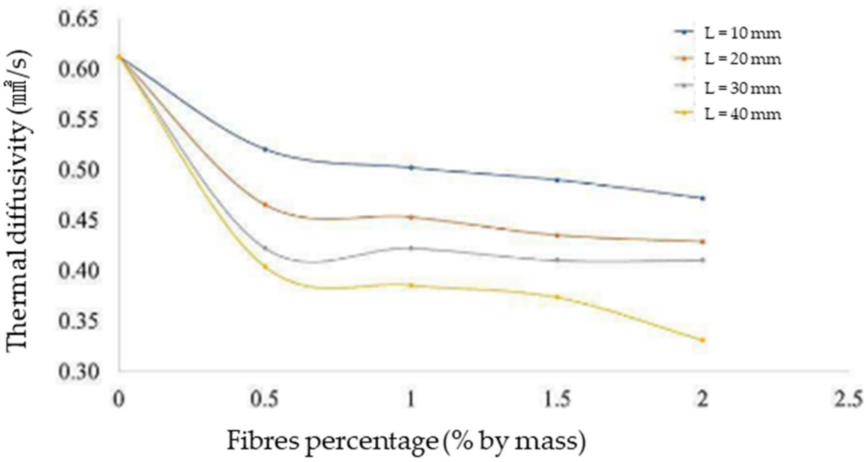


Figure 42. Thermal diffusivity of the composites as a function of the percentage and length of DPFs. Reprinted from [30].

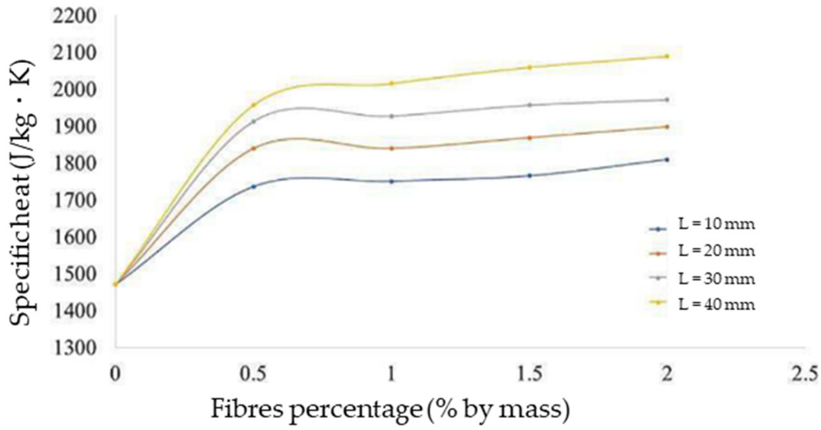


Figure 43. Specific heat capacity of the composites as a function of the percentage and length of DPFs. Reprinted from [30].

According to previous studies, thermal conductivity and thermal diffusivity decreased, and specific heat capacity increased by adding natural fibres. Rachedi and Kriker [30] stated that the specimens that contained 2% of DPFs resulted in 50% lower thermal conductivity than the control specimens. Fulfilling the standard requirement of mechanical strength (ACI 318) becomes difficult because it needed to incorporate a high volume of natural fibres into the mixture to improve thermal properties. Therefore, the use of these mixes of cementitious composites as a structural member is not recommended.

6. Conclusions

The addition of natural fibres into cementitious composites as reinforcement material has many advantages and can be an alternative material of synthetic fibres. Furthermore, natural fibres tend to be degraded earlier, and the quality is not as stable as that of synthetic fibres. Therefore, research regarding these points should be conducted in the future. This review paper is a summary of the recent studies that are related to the applications of coconut and palm oil fibres into cement-based materials. The following conclusions could be drawn from this review.

(1) Coconut and palm oil fibres consist of approximately 33.2 to 65% cellulose, 11.6 to 33.5% hemicellulose and 13.2 to 45% lignin.
(2) The bridging effect of natural fibres prevents the expansion of cracking of the cement matrix.
(3) The most influencing factors of natural fibres on the mechanical properties of cement-based materials include the tensile strength of the natural fibre and the adhesion strength between the fibre and the cement matrix.
(4) The pre-treatment of natural fibre, such as alkaline, silane and hot-water treatment, will remove impurities and silica particles from the surface of fibres and improve the adhesion strength between the natural fibre and the cement matrix.
(5) Generally, natural fibres increase the mechanical properties of the cementitious composite. However, beyond a certain percentage, the mechanical properties dramatically decrease. This phenomenon occurs because natural fibres involve lots of air voids when mixed with a cement matrix, and these air voids cause strength reduction.
(6) Natural fibres have high water absorption, and it would affect the workability of the fresh mixture negatively.
(7) The incorporation of more natural fibre in the cementitious composite improves the thermal properties.

As a future outlook of this research area, data on the durability and thermal properties of coconut and palm oil fibre reinforced cementitious composites are insufficient. Therefore, further studies are needed to understand the influence of these types of fibres on the thermal properties, such as thermal conductivity, thermal diffusivity, specific heat, and durability assessments, such as water absorption, drying shrinkage, creep, acid and sulphate attacks of the natural fibre reinforced cementitious materials.

Author Contributions: Conceptualization, E.F. and P.S.; methodology, E.F. and P.S.; validation, E.F., P.S., H.Y.B.K. and Z.I.; formal analysis, E.F. and P.S.; investigation, E.F.; resources, E.F.; data curation, E.F. and P.S.; writing—original draft preparation, E.F.; writing—review and editing, E.F., P.S., H.Y.B.K. and Z.I.; supervision, P.S. and Z.I.; funding acquisition, P.S. and H.Y.B.K.; project administration, P.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research is supported by Universiti Tenaga Nasional Internal Research Grant OPEX (J5100D4103-BOLDREFRESH2025-CENTRE OF EXCELLENCE).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available within the article.

Acknowledgments: The authors would like to express their gratitude for the provided support by Universiti Malaya and Universiti Tenaga Nasional.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Momoh, E.O.; Osofero, A.I. Behaviour of oil palm broom fibres (OPBF) reinforced concrete. *Constr. Build. Mater.* **2019**, *221*, 745–761. [CrossRef]
2. Kobayakawa, S. Man-hour survey and analysis of the labor productivity of on-site work using the reinforced precast concrete frame method, survey and study of labor productivity of the reinforced precast concrete frame method (part 1). *J. Archit. Plan.* **2001**, *66*, 199–205. [CrossRef]
3. Kunieda, M.; Uchida, Y.; Rokugou, K. Trends in the development of fibre reinforced cement composites; The properties of Materials Aiming for application that makes use of cement and concrete. *Cem. Concr.* **2007**, *726*, 7–12.
4. Venkateshwaran, N.; Elayaperumal, A.; Sathiya, G.K. Prediction of tensile properties of hybrid-natural fiber composites. *Compos. Part B Eng.* **2012**, *43*, 793–796. [CrossRef]
5. de Carvalho Bello, C.B.; Cecchi, A. Experiments on natural fibers: Durability and mechanical properties. *Adv. Mater. Process. Technol.* **2017**, *3*, 632–639. [CrossRef]
6. Magdamo, R.V. *An Analysis of the Abaca Natural Fiber in Reinforcing Concrete Composites as a Construction Material in Developing Countries*; ProQuest Dissertations Publishing: Ann Arbor, MI, USA, 1988.
7. Agustin, R.; Robles-Austriaco, L. Technological development of low cost materials in ASEAN countries. *J. Ferrocem.* **1990**, *20*, 265–279.
8. The Editors of Encyclopaedia. "Natural Fibre". Encyclopedia Britannica. 2020. Available online: https://www.britannica.com/topic/natural-fiber (accessed on 19 October 2021).
9. Mase, K. Application of Bio-plastics to Automotive Parts. *Senni Gakkai Shi* **2008**, *64*, 276–278. [CrossRef]
10. Daniyan, A.; Ogundare, O.; AttahDaniel, B.; Babatope, B. Effect of palm oil as corrosion inhibitor on ductile iron and mild steel. *Pac. J. Sci. Technol.* **2011**, *12*, 45–53.
11. Chiew, Y.L.; Shimada, S. Current state and environmental impact assessment for utilizing oil palm empty fruit bunches for fuel, fiber and fertilizer—A case study of Malaysia. *Biomass Bioenergy* **2013**, *51*, 109–124. [CrossRef]
12. Castro, J.; Naaman, A.E. Cement mortar reinforced with natural fibers. *J. Ferrocem.* **1981**, *11*, 285–301.
13. Hashim, M.H.B.M. Coconut Fiber Reinforced Wall Panelling System. Unpublished Master's Thesis, University of Technology Malaysia, Skudai, Johor, Malaysia, 2005.
14. Brose, A.; Kongoletos, J.; Glicksman, L. Coconut fiber cement panels as wall insulation and structural diaphragm. *Front. Energy Res.* **2019**, *7*, 9. [CrossRef]
15. Pan, H.; Liu, Y. Properties of natural fiber cement boards for building partitions. In *Challenges, Opportunities and Solutions in Structural Engineering and Construction*; CRC Press: Boca Raton, FL, USA, 2009; pp. 617–622.
16. Li, Z.; Wang, L.; Wang, X.A. Cement Composites Reinforced with Surface Modified Coir Fibers. *J. Compos. Mater.* **2007**, *41*, 1445–1457. [CrossRef]
17. Ali, M. Coconut fibre: A versatile material and its applications in engineering. *J. Civ. Eng. Constr. Technol.* **2011**, *2*, 189–197.
18. Embrandiri, A.; Singh, R.P.; Ibrahim, H.M.; Ramli, A.A. Land application of biomass residue generated from palm oil processing: Its potential benefits and threats. *Environmentalist* **2012**, *32*, 111–117. [CrossRef]
19. Quiñones-Bolaños, E.; Gómez-Oviedo, M.; Mouthon-Bello, J.; Sierra-Vitola, L.; Berardi, U.; Bustillo-Lecompte, C. Potential use of coconut fibre modified mortars to enhance thermal comfort in low-income housing. *J. Environ. Manag.* **2021**, *277*, 111503. [CrossRef] [PubMed]

20. Bui, H.; Sebaibi, N.; Boutouil, M.; Levacher, D. Determination and Review of Physical and Mechanical Properties of Raw and Treated Coconut Fibers for Their Recycling in Construction Materials. *Fibers* **2020**, *8*, 37. [CrossRef]
21. Ardanuy, M.; Claramunt, J.; Toledo Filho, R.D. Cellulosic fiber reinforced cement-based composites: A review of recent research. *Constr. Build. Mater.* **2015**, *79*, 115–128. [CrossRef]
22. Ahmad, Z.; Saman, H.; Tahir, P. Oil Palm Trunk Fiber as a Bio-Waste Resource for Concrete Reinforcement. *Int. J. Mech. Mater. Eng.* **2010**, *5*, 199–207.
23. Bonnet-Masimbert, P.-A.; Gauvin, F.; Brouwers, H.; Amziane, S. Study of modifications on the chemical and mechanical compatibility between cement matrix and oil palm fibres. *Results Eng.* **2020**, *7*, 100150. [CrossRef]
24. Ozerkan, N.G.; Ahsan, B.; Mansour, S.; Iyengar, S.R. Mechanical performance and durability of treated palm fiber reinforced mortars. *Int. J. Sustain. Built Environ.* **2013**, *2*, 131–142. [CrossRef]
25. Ferdiansyah, T.; Razak, H.A. Mechanical properties of black sugar palm fiber-reinforced concrete. *J. Reinf. Plast. Compos.* **2011**, *30*, 994–1004. [CrossRef]
26. Rasoul, Z.S.; Juoi, J.M.; Mohamad, M.; Fawzi, N.M. Date Palm Fiber (DPF) and its Composites: A Comprehensive Survey. *Int. J. Adv. Sci. Technol.* **2020**, *29*, 1776–1788.
27. Olaoye, R.; Oluremi, J.; Ajamu, S. The use of fibre waste as complement in concrete for a sustainable environment. *Innov. Syst. Des. Eng.* **2013**, *4*, 91–98.
28. Hwang, C.-L.; Tran, V.-A.; Hong, J.-W.; Hsieh, Y.-C. Effects of short coconut fiber on the mechanical properties, plastic cracking behavior, and impact resistance of cementitious composites. *Constr. Build. Mater.* **2016**, *127*, 984–992. [CrossRef]
29. Momoh, E.O.; Osofero, A.I. Recent developments in the application of oil palm fibers in cement composites. *Front. Struct. Civ. Eng.* **2020**, *14*, 94–108. [CrossRef]
30. Rachedi, M.; Kriker, A. Thermal Properties of Plaster Reinforced with Date Palm Fibers. *Civ. Environ. Eng.* **2020**, *16*, 259–266. [CrossRef]
31. Shafigh, P.; Asadi, I.; Akhiani, A.R.; Mahyuddin, N.B.; Hashemi, M. Thermal properties of cement mortar with different mix proportions. *Mater. De Construcción* **2020**, *70*, 224. [CrossRef]
32. Ramakrishna, G.; Sundararajan, T. Impact strength of a few natural fibre reinforced cement mortar slabs: A comparative study. *Cem. Concr. Compos.* **2005**, *27*, 547–553. [CrossRef]
33. John, V.; Cincotto, M.; Sjöström, C.; Agopyan, V.; Oliveira, C. Durability of slag mortar reinforced with coconut fibre. *Cem. Concr. Compos.* **2005**, *27*, 565–574. [CrossRef]
34. Hill, C.A.; Khalil, H.A.; Hale, M.D. A study of the potential of acetylation to improve the properties of plant fibres. *Ind. Crop. Prod.* **1998**, *8*, 53–63. [CrossRef]
35. Ngadiman, N.; Kaamin, M.; Kadir, A.A.; Sahat, S.; Zaini, A.; Zentan, S.R.N.; Ahmad, N.A.; Amran, W.H.A.W. Panel board from coconut fibre and pet bottle. In Proceedings of the E3S Web of Conferences, Johor, Malaysia, 19 March 2018; p. 01014.
36. Ramakrishna, G.; Sundararajan, T. Studies on the durability of natural fibres and the effect of corroded fibres on the strength of mortar. *Cem. Concr. Compos.* **2005**, *27*, 575–582. [CrossRef]
37. Femandez, J. Flax fiber reinforced concrete-a natura1 fiber biocomposite for sustainable building materials. *WIT Trans. Built Environ.* **2002**, *59*, 15. [CrossRef]
38. Rao, K.M.M.; Rao, K.M. Extraction and tensile properties of natural fibers: Vakka, date and bamboo. *Compos. Struct.* **2007**, *77*, 288–295. [CrossRef]
39. Ramli, M.; Kwan, W.H.; Abas, N.F. Strength and durability of coconut-fiber-reinforced concrete in aggressive environments. *Constr. Build. Mater.* **2013**, *38*, 554–566. [CrossRef]
40. Agopyan, V.; Savastano, H., Jr.; John, V.; Cincotto, M. Developments on vegetable fibre–cement based materials in São Paulo, Brazil: An overview. *Cem. Concr. Compos.* **2005**, *27*, 527–536. [CrossRef]
41. Khalil, H.A.; Hanida, S.; Kang, C.; Fuaad, N.N. Agro-hybrid composite: The effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. *J. Reinf. Plast. Compos.* **2007**, *26*, 203–218. [CrossRef]
42. Lertwattanaruk, P.; Suntijitto, A. Properties of natural fiber cement materials containing coconut coir and oil palm fibers for residential building applications. *Constr. Build. Mater.* **2015**, *94*, 664–669. [CrossRef]
43. Dawood, E.T.; Ramli, M. Properties of High-Strength Flowable Mortar Reinforced with Palm Fibers. *ISRN Civ. Eng.* **2012**, *2012*, 718549. [CrossRef]
44. Ahmad, M.H.; Mohd Noor, N. Mix design of palm oil fiber concrete. In Proceedings of the International Conference on Civil Engineering, Pahang, Malaysia, 12–14 May 2008.
45. Ahmad, Z.; Ibrahim, A.; Tahir, P. Drying shrinkage characteristics of concrete reinforced with oil palm trunk fiber. *Int. J. Eng. Sci. Technol.* **2010**, *2*, 1441–1450.
46. Abdullah, A.; Abdullah, M.M.A.B.; Kamarudin, H.; Ghazali, C.M.R.; Salleh, M.A.A.M.; Sang, P.K.; Muhammad Faheem, M.T. Study on the properties of oil palm trunk fiber (OPTF) in cement composite. *Appl. Mech. Mater.* **2013**, *421*, 395–400. [CrossRef]
47. Yan, Y. 2-Developments in fibers for technical nonwovens. In *Advances in Technical Nonwovens*; Kellie, G., Ed.; Woodhead Publishing: Sawston, UK, 2016; pp. 19–96.
48. Momoh, E.O.; Osofero, A.I.; Menshykov, O. Physicomechanical Properties of Treated Oil Palm-Broom Fibers for Cementitious Composites. *J. Mater. Civ. Eng.* **2020**, *32*, 04020300. [CrossRef]

49. Abdullah, A. Composite Cement Reinforced Coconut Fiber: Physical and Mechanical Properties and Fracture Behavior. *Aust. J. Basic Appl. Sci.* **2011**, *5*, 1228–1240.
50. Neville, A.M. *Properties of Concrete*, 5th ed.; Longman: London, UK, 2011.
51. Naamandadin, N.A.; Rosdi, M.S.; Mustafa, W.A.; Shahrol Aman, M.N.S.; Saidi, S.A. Mechanical behaviour on concrete of coconut coir fiber as additive. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *932*, 012098. [CrossRef]
52. Ramli, M.S.; Abas, N.F.; Othuman Mydin, M.A. Investigation of Mechanical Properties of Coconut Fiber as a Concrete Admixture. *MATEC Web Conf.* **2014**, *17*, 01018. [CrossRef]
53. Sathiparan, N.; Rupasinghe, M.N.; H.M. Pavithra, B. Performance of coconut coir reinforced hydraulic cement mortar for surface plastering application. *Constr. Build. Mater.* **2017**, *142*, 23–30. [CrossRef]
54. Shfafi, S.M.S.M. Effect of Coconut Fibre in Concrete and to Improve the Workability by Incorporating an Admixture. Engineering. 2016. Available online: https://www.slideshare.net/HSAAMHSAAM/effect-of-coconut-fibre-in-concrete-and-to-improve-the (accessed on 19 October 2021).
55. Khoudja, D.; Taallah, B.; Izemmouren, O.; Aggoun, S.; Herihiri, O.; Guettala, A. Mechanical and thermophysical properties of raw earth bricks incorporating date palm waste. *Constr. Build. Mater.* **2021**, *270*, 121824. [CrossRef]
56. Lee, S.W.; Oh, C.L.; Zain, M.R.M.; Yahya, N.A. The Use of Oil Palm Fiber as Additive Material in Concrete. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *431*, 042012. [CrossRef]
57. Ramli, M.; Dawood, E.T. Effects of palm fiber on the mechanical properties of lightweight concrete crushed brick. *Am. J. Appl. Sci.* **2011**, *3*, 489–493. [CrossRef]
58. Benmansour, N.; Agoudjil, B.; Gherabli, A.; Kareche, A.; Boudenne, A. Thermal and mechanical performance of natural mortar reinforced with date palm fibers for use as insulating materials in building. *Energy Build.* **2014**, *81*, 98–104. [CrossRef]
59. Tioua, T.; Kriker, A.; Salhi, A.; Barluenga, G. *Effect of Hot-Dry Environment on Fiber-Reinforced Self-Compacting Concrete*; AIP Publishing: College Park, MD, USA, 2016. [CrossRef]
60. Suhaili, S.S.; Mydin, M.A.O.; Awang, H. Influence of Mesocarp Fibre Inclusion on Thermal Properties of Foamed Concrete. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2021**, *8*, 1–11. [CrossRef]
61. Awang, H.; Ahmad, M.H. Durability properties of foamed concrete with fiber inclusion. *World Acad. Sci. Eng. Technol. Int. J. Civ. Environ. Struct. Constr. Archit. Eng.* **2014**, *8*, 269–272.