INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 13 NO. 1 (2022) 9-24

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Mechanical and Durability Properties of Foamed Concrete with the Addition of Oil Palm Trunk Fibre

Md Azree Othuman Mydin[1*]

[1]School of Housing, Building and Planning,
Universiti Sains Malaysia 11800, Penang, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2022.13.01.002
Received 23 March 2021; Accepted 05 March 2022; Available online 16 May 2022

Abstract: Nowadays, in Malaysia, one of the country's challenges is the improper management and disposal of solid waste. The leading sector that generates most of the solid waste in Malaysia is the agricultural sector from oil palm fibre, similar to oil palm trunk fibre, which is also be used as an additive in producing foamed concrete (FC). However, FC presents a weakness in tension, which can be reduced by adding an adequate volume of waste biomass by-product such as oil palm trunk (OPT) fibre. Accordingly, this study was undertaken to investigate the potential of utilising OPT fibre as a reinforcement in FC. There were four different volume fractions of OPT fibre: 0.15%, 0.30%, 0.45%, and 0.60% used as an additive to the FC mix. Two densities, 600 kg/m^3 and 1200 kg/m^{3,} were cast and tested. All FC specimens were then prepared and left to cure and exposed to the elements for 7, 28, and 56 days. In this study, to properties were examined: mechanical and durability properties. The results showed that the addition of OPT fibre in FC improved the compressive strength, flexural strength, tensile strength, water absorption, drying shrinkage, porosity and ultrasonic pulse velocity of the FC. OPT's surface roughness was proved beneficial for fibre to matrix interfacial bonding since a coarser surface permit OPT fibre and matrix interlocking in the hardened cement matrix. Based on the results of this study for 600 kg/m^3 density, 0.30% volume fraction was the optimum amount added to the FC to achieve the best durability and mechanical properties. While for 1200 kg/m3, 0.45% volume fraction of OPT was the optimum percentage.

Keywords: Foamed concrete, compressive strength, flexural, tensile, porosity, water absorption

1. Introduction

Foamed concrete (FC) as a material in the construction industry is not new since it was initially patented in 1923 though on a limited scale (Moon *et al.*, 2015). It was only until the late 1970s that the material started to be used in the Netherlands for ground engineering applications and voids filling works (Müllera *et.al.*, 2014). In 1987 a full-scale assessment on the application of lightweight foam concrete (LFC) as a trench reinstatement was conducted in the United Kingdom (UK), and the achievement of this trial led to the extensive application of FC for trench reinstatement, in which other applications soon followed (Lim *et al.*, 2014). Since then, FC as a building material has become more prominent and widespread in expanding the production and range of applications (Jalal *et al.*, 2017). Over the last 20 years, FC has primarily been used for bulk filling, trench reinstatements, backfill to retaining walls and bridge abutments, insulation to foundations and roof tiles, sound insulation, stabilising soils (especially in the construction of embankment slopes), grouting for tunnel works, sandwich filling for precast units and pipeline infill (Mohammad Hosseini *et. al*, 2016). However, there has been a growing interest in using FC as a lightweight non-structural and semi-structural material in

**Corresponding author: azree@usm.my*

building construction (Sari and Sani, 2017) to take advantage of its lightweight and good insulation properties during the last few years (Thakrele, 2014).

However, FC is known to be a reasonably brittle material when exposed to normal stresses and impact loads, where its tensile strength is about one-tenth of its compressive strength (Ramamurthy *et al.,* 2009). As a result, FC flexural members could not support such loads that usually occur during their service life for these characteristics (Mahzabin *et al.,* 2018). In the past, FC members reinforced with continuous reinforcing bars were used to withstand tensile stresses and compensate for the lack of ductility and strength (Kim *et al*., 2010). Furthermore, steel reinforcement was utilised to overcome high potentially tensile stresses and shear stresses at a critical location in FC members (Tangchirapat and Jaturapitakkul, 2016). Even though the addition of steel reinforcement increases the strength of FC, the development of micro-cracks needs to be controlled to fabricate the concrete with homogenous tensile properties (Suhendro, 2014).

Therefore, fibre is seen as a solution to develop FC with enhanced flexural and tensile strength, which is a new form of binder that can combine Portland cement in bonding with cement matrices. The fibres are mostly discontinuous, randomly distributed throughout the cement matrices (Elrahman *et al.,* 2019). The inclusion of fibres in FC is to delay and control the tensile cracking of composite material (Munir *et al.,* 2015). Fibres thus transform the inherent unstable tensile crack propagation to slow controlled crack growth. This crack controlling properties of the fibre helped to reinforce the delays and the initiation of flexural and shear cracking (Memon *et al*., 2018). It imparts extensive post cracking behaviour and extensively enhances the ductility of the composite (Jhatial *et al.,* 2017).

Fibres, which are randomly t random dispersed throughout the FC, could overcome cracks and control shrinkage more efficiently (Hamad, 2014). These materials have exceptional combinations of strength and energy absorption capacity. In general, fibre reinforcement is not a substitution for conventional steel reinforcement since the fibres and steel reinforcement have their own role in FC technology (Othuman Mydin *et al.,* 2016), and there are many applications to which both fibres and continuous reinforcing steel bars can be used together (Muthusamy and Zamri, 2016). However, fibres are not efficient in withstanding the tensile stresses compared to conventional steel reinforcement (Serri *et al.,* 2014). Fibres are more closely spaced than steel reinforcements, which are better in controlling cracks and shrinkage. As a result, conventional steel reinforcements are used to amplify the load-bearing capacity of the FC member since fibres are more effective in crack control (Kamaruddin *et al.,* 2018).

In Malaysia, the growth in oil palm plantations has produced significant waste products during the replanting process, especially oil palm frond and oil palm trunk (OPT). Nowadays, oil palm fibre waste contributes to about 70% of the overall total waste in Malaysia (Momeen *et al.,* 2016). Fig. 1 shows the actual and crosscut end of oil palm trunk. Given that oil palm fibre is good in tension and low in density, scientists and engineers worldwide have actively been researching the potential use of this fibre on concrete structure material. The oil palm fibre added to concrete can also be applied to lightweight concretes in determining the optimum composition of this concrete. Hence this research explores the potential utilisation of OPT fibre in FC.

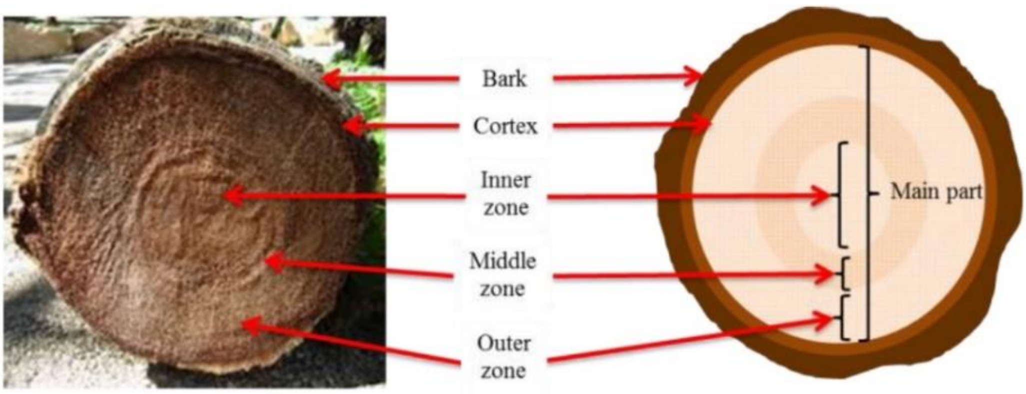


Fig. 1 - Actual end and crosscut end of oil OPT

2.0 Material Constituents, Mix Proportion and Tests

2.1 Ordinary Portland Cement

Ordinary Portland cement (OPC) was used in this study, complying with the BS 12 (BS12, 1996) standard. This product is available in 50 kg bags and in bulk. Fine inorganic material forms a paste once water is added to the mixture.

2.2 Fine Sand

The fine aggregate used in this study was natural fine sand supplied by a local distributor. Sieve analysis was conducted to assess the suitability of the sand to use according to BS882 (BS882, 1992) and the result is shown in Fig. 2. Fine sand was used with a size of 1.18 mm to improve the FC flow characteristics and stability.

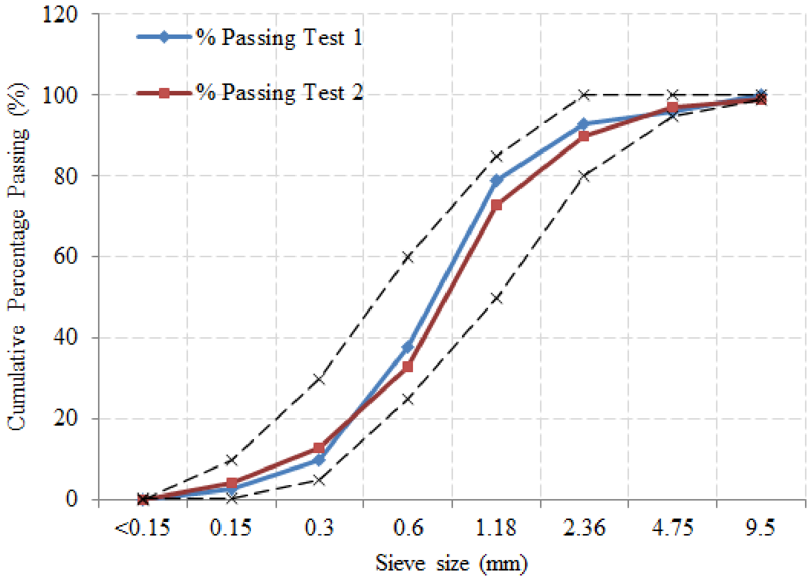


Fig. 2 - Sieve analysis result of fine sand

2.3 Stable Foam

The foam was produced from a generator using foam agents, in which the bubbles were relatively small in size. The protein agent used for this study was Noraite-PA-1, at a ratio of 1:33 to the volume of water. The clean water used in the mix together with the protein agent was to create a good foaming agent. The density of FC was determined by the volume of foam added into the mix. The stability of foam is important in producing FC since the generator will act as a medium to transfer the agent into the stable foam. The weight of the foam used in this investigation varied between 60-80 g/litre.

2.4 Oil Palm Trunk Fibre

This oil palm trunk (OPT) fibre was cleaned five times with clean tap water to remove any debris. The fibre was then dried for 2 days (see Fig. 3). The volume fraction of the fibre used was 0.15%, 0.30%, 0.45%, 0.60% and 0% of the total weight mix volume. Fig. 4 illustrates the morphological details of OPT fibre structures particularly the parenchyma tissues and Fig. 5 shows the transverse section of OPT fibre. Table 1 and Table 2 show the chemical composition and physical properties of OPT fibre used in this study respectively.

Fig. 3 - Oil palm trunk fibre was dried for two days

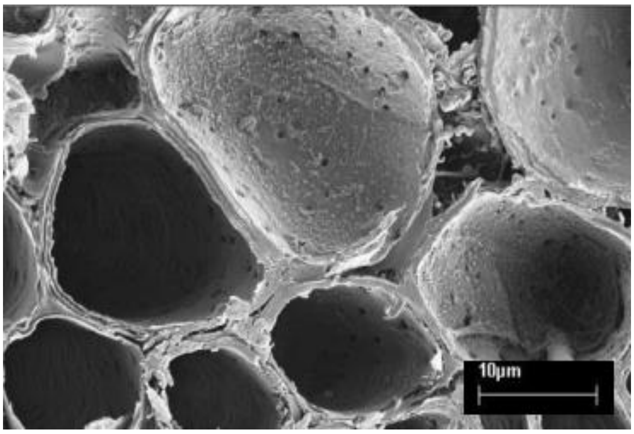


Fig. 4 - Morphology details of oil palm trunk (OPT) fibre structures

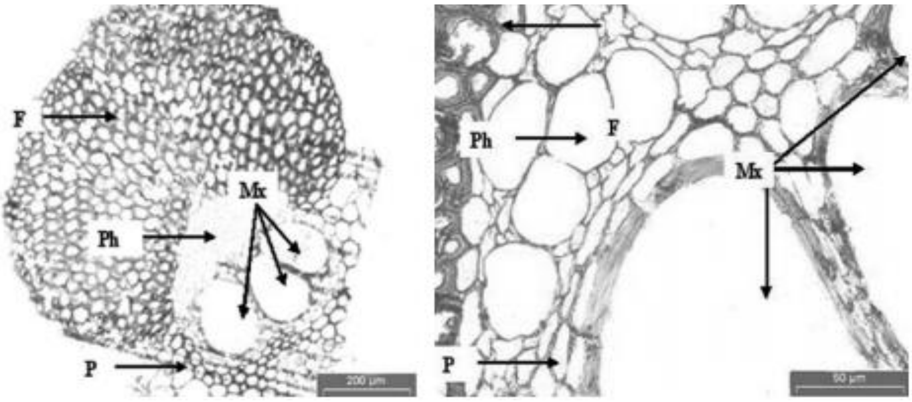


Fig. 5 - Transverse section of oil palm trunk fibre

Table 1 - Chemical composition of OPT

Composition	%, dry weight
Cellulose	31
Hemicellulose	15
Holocellulose	42
Lignin	21
Xylose	15
Glucose	30
Ash	2

Table 2 - Physical properties of OPT

Component	Properties
Fibre length	15mm
Fibre diameter	148 um
Lumen width	17.45 um
Density	0.82 g/cm^3
Runkel ratio	0.275
Fibril angle (º)	42

2.5 Mix Design

A total of 10 mixes were prepared for this research. The mix design proportion for 600 kg/m³ and 1200 kg/m³ is shown in Table 3. The different per cent of OPT used was 0.15%, 0.30%, 0.45%, 0.60% and 0%. For all mixes, the sand-cement ratio was fixed at 1:1.5, and the water-cement ratio was 0.45.

Table 3 - Mix design

Sample	Mix Density (kg/m^3)	Mix Ratio (S:C:W)	Cement (kg)	Fine sand (kg)	Water (kg)
Control mix-600	600	1:1.5:0.45	14.11	21.17	6.35
0.15% OPF-600	600	1:1.5:0.45	14.11	21.17	6.35
0.30% OPF-600	600	1:1.5:0.45	14.11	21.17	6.35
0.45% OPF-600	600	1:1.5:0.45	14.11	21.17	6.35
0.60% OPF-600	600	1:1.5:0.45	14.11	21.17	6.35
Control mix-1200	1200	1:1.5:0.45	27.40	41.09	12.33
0.15% OPF-1200	1200	1:1.5:0.45	27.40	41.09	12.33
0.30% OPF-1200	1200	1:1.5:0.45	27.40	41.09	12.33
0.45% OPF-1200	1200	1:1.5:0.45	27.40	41.09	12.33
0.60% OPF-1200	1200	1:1.5:0.45	27.40	41.09	12.33

2.6 Curing Process

After 24 h, all specimens were demoulded and wrapped with a plastic sheet before testing for 7, 28, and 56 days. The curing purpose is to maintain the proper moisture and temperature of the concrete to ensure continuous hydration (see Fig. 6). Curing was also undertaken to improve the strength of the concrete along with the age of the concrete to achieve the design strength of the FC.

Fig. 6 - All specimens were wrapped with a plastic sheet before the testing day

2.7 Experimental Arrangement

The compression test was conducted on a 100 mm x 100 mm x 100 mm cube according to the BS 12390: Part 3 (BS12390-3, 2011) (see Fig. 7), and the flexural test was performed on a 30 mm x 100 mm x 350 mm prism according to ASTM C293 (ASTM C293, 2016) (see Fig. 8). The tensile test was conducted on a 100 mm diameter x 200 mm height cylinder, according to ASTM C496 (ASTM C496, 2017) (see Fig. 9).

Fig. 7 - Compression Test according to BS EN 12390: Part 3

Fig. 8 - The flexural test was performed according to ASTM C293

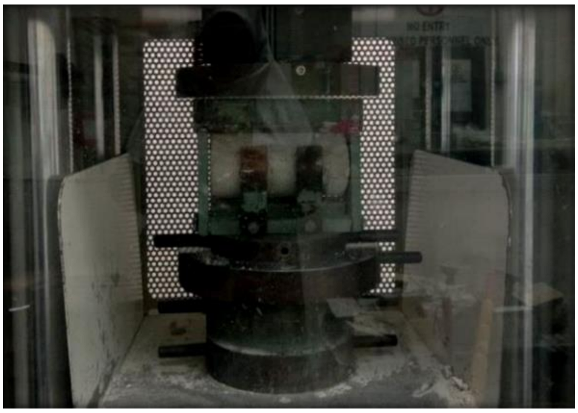


Fig. 9 - The splitting tensile test was carried out according to ASTM C-496

The water absorption test was conducted on a 75 mm diameter x 100 mm height cylinder according to BS 1881: Part 122 (BS1881-122, 1983) (see Fig. 10), and the porosity test was conducted according to BS 1881: Part 122 (BS1881-122, 1983) on a 45 mm diameter x 50 mm height cylinder (see Fig. 11). The drying shrinkage test was performed on a 5 mm x 75 mm x 275 mm prism according to ASTM C878 (ASTM C878, 2014) (see Fig. 12), and the ultrasonic pulse velocity (UPV) test was performed on a 100 mm x 100 mm x 500 mm prism according to BS 12504: Part 4 (BS12504-4, 2004)

Fig. 10 - Water absorption test was performed according to BS 1881: Part 122

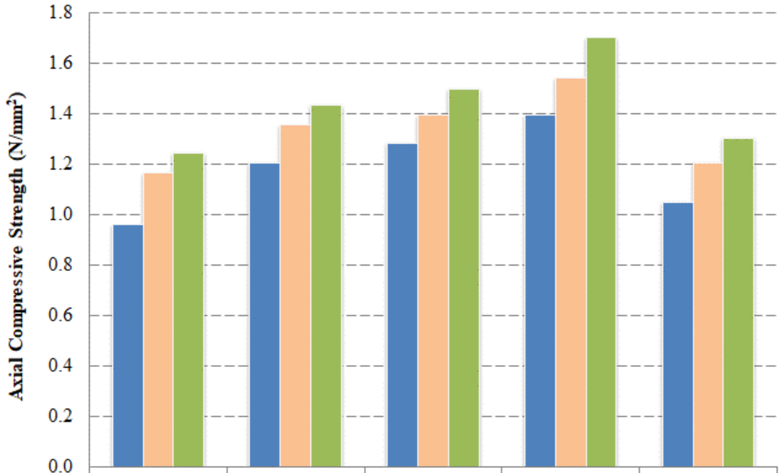
Fig. 11- Porosity test was performed according to BS 1881: Part 122

Fig. 12 - Shrinkage test was carried out according to ASTM: C 878

3.0 Results and Discussion

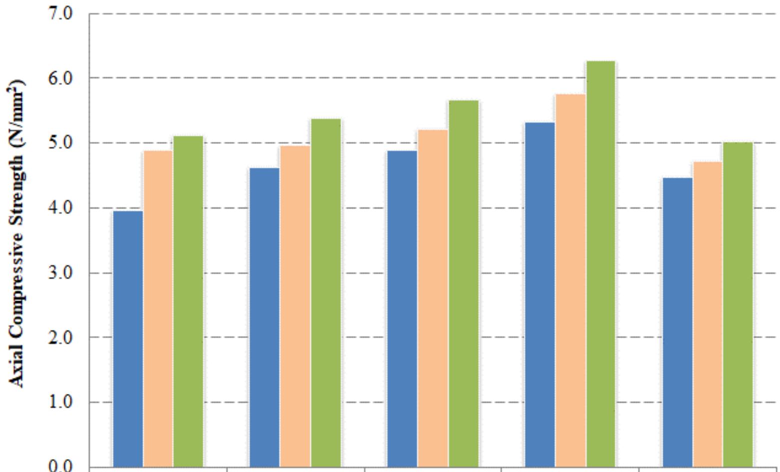
3.1 Compressive Strength

Figures 13 and 14 display the result of the control specimen and LFC's axial compressive strength with the additive of OPT fibre; 600 kg/m³ and 1200 kg/m^3 densities. As can be seen from these figures, the control specimen (without the inclusion of OPT) has lower compressive strength compared to the LFC with the addition of OPT. The improvement of the compressive strength was observed from day 7 to day 56. The highest result of compressive strength with 0.45% OPT for both densities was then compared to other percentages of OPT, which was 1.70 N/mm² for 600 kg/m³ and 6.27 N/mm² for 1200 kg/m³. Accordingly, the OPT fibre helped in preventing the promulgation of cracking in the plastic state in the cement matrix when the load was applied. Furthermore, the lowest result of compressive strength, the control specimen, was 1.24 N/mm² for 600 kg/m³, and 0.60% of OPT was 5.02 N/mm² for 1200 kg/m³. Aside from that, 0.30% of OPT was shown for 1.49 N/mm² for 600 kg/m³ and 5.67 N/mm² for 1200 kg/m³. Next, the 0.15% of OPT showed 1.43 N/mm² for 600 kg/m³ and 5.38 N/mm² for 1200 kg/m³. From Figures 13 and 14, it clearly shows that specimens with 0.45% of OPT give the optimum compressive strength and the strength dropped when the OPT fibre content is further from 0.45% to 0.60%. Specimens with 0.45% of OPT fibre content gave the highest compressive strength among all the specimens and this may be related with the homogeneous dispersion of OPT in FC. Small amount of fibre content can be dispersed well in FC thus increase the packing density of cement composite and this will then increase the compressive strength. The reduction in compressive strength when up to certain fibre content may be triggered by the creation of air void within the mixture with fairly high fibre content (Majid *et al*., 2012). As fibre content continuous to upsurge, fibre agglomerated and lead to the decrease in compressive strength. According to Sumit *et al.* (2013), increase in OPT fibre content may also lead to reduction of bonding and disintegration. In other words, increase in fibre content may reduce the volume proportion of matrix mix and causes a decreasing in compressive strength (Al Rim *et al.*, 1999). In general, it can be seen that the added fibres to the FC showed better compressive strength over the control specimen since natural fibres have a strong resistance to compression. Based on the data, the use of a higher density of FC increases the compressive strength.



	Control	0.15-OPT	0.30-OPT	0.45-OPT	0.60-OPT
Day-7	0.96	1.20	1.28	1.40	1.05
Day-28	1.16	1.36	1.40	1.54	1.20
Day-56	1.24	1.43	1.49	1.70	1.30

Fig. 13 - Compressive strength result of 600 kg/m³ density

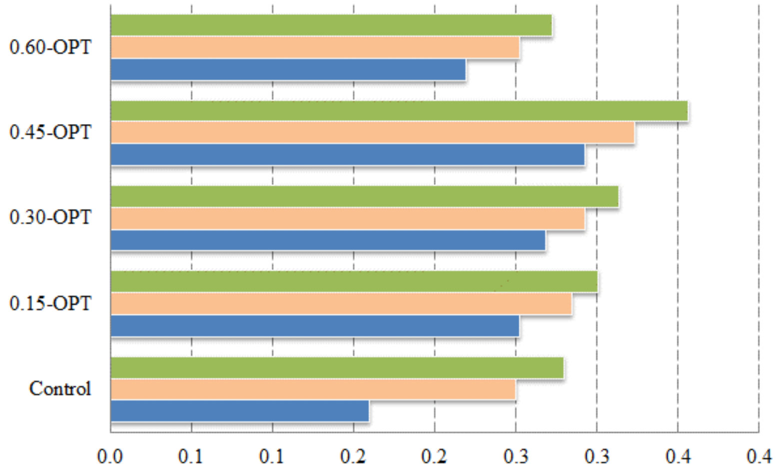


	Control	0.15-OPT	0.30-OPT	0.45-OPT	0.60-OPT
Day-7	3.95	4.62	4.89	5.32	4.47
Day-28	4.88	4.96	5.22	5.75	4.71
Day-56	5.12	5.38	5.67	6.27	5.02

Fig. 14 - Compressive strength result of 1200 kg/m³ density

3.2 Flexural Strength

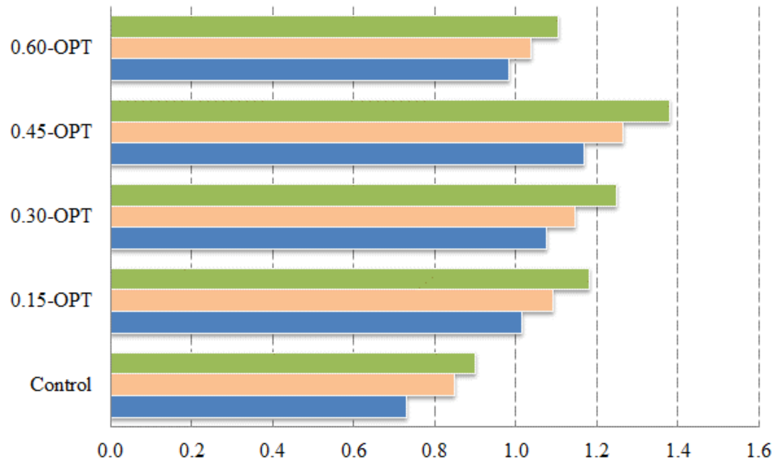
Figures 15 and 16 show the flexural strength for both densities. The graph shows that 0.45% OPF volume fraction contributed to the highest flexural strength, which is 0.36 N/mm² for 600 kg/m³ density and 1.38 N/mm² for 1200 kg/m³ density. OPT is a reinforcing agent, given its biodegradable attributes. OPT has a high failure strain which can give superior compatibility between the fibres and the matrix. For all the densities used in this research, the increase in flexural strength increased the OPT fibre percentage. For example, 0.15%, 0.30% and 0.60% of OPT fibre compared to the control sample. However, the flexural strength of FC decreases when exceeding 0.45%. This is because of an incomplete composite. Furthermore, the lowest flexural strength was for the control specimen for 0.16 N/mm² for 600 kg/m³ and 0.73 N/mm² for 1200 kg/m³. Next, as shown in the graph, for the 0.15% of OPT, it shows a difference of 0.25 N/mm² for 600 kg/m³ and 1.02 N/mm² for 1200 kg/m³. Other than that, 0.30% of OPT showed 0.27 N/mm² for 600 kg/m³ and 1.08 N/mm² for 1200 kg/m³. Furthermore, 0.60% of OPT showed 0.22 N/mm² for 600 kg/m³ and 1.17 N/mm² for 1200 kg/m³. Overall, the FC was shown to be good in terms of compression but brittle under flexural strength. Accordingly, it can be concluded that the flexural strength of lightweight concrete improved with the addiction of OPT fibre as reinforcement for the concrete.



	Control	0.15-OPT	0.30-OPT	0.45-OPT	0.60-OPT
Day-56	0.28	0.30	0.31	0.36	0.27
Day-28	0.25	0.28	0.29	0.32	0.25
Day-7	0.16	0.25	0.27	0.29	0.22

Flexural Strength (N/mm²)

Fig. 15 - Flexural strength result of 600 kg/m³ density



	Control	0.15-OPT	0.30-OPT	0.45-OPT	0.60-OPT
Day-56	0.90	1.18	1.25	1.38	1.10
Day-28	0.85	1.09	1.15	1.27	1.04
Day-7	0.73	1.02	1.08	1.17	0.98

Flexural Strength (N/mm²)

Fig. 16 - Flexural strength result of 1200 kg/m³ density

3.3 Tensile Strength

Figures 17 and 18 show the result of splitting tensile strength of lightweight FC with the additive of OPT fibre for 600 kg/m³ and 1200 kg/m³. It can be seen that FC without OPT has lower compressive strength compared to the lightweight FC with the addition of OPT. The graph shows that 0.45% OPF volume fraction contributed to the highest splitting tensile strength, which was 0.23 N/mm² for 600 kg/m³ density and 0.88 N/mm² for 1200 kg/m³ density. Furthermore, the lowest result for the compressive strength for the control sample was 0.17 N/mm² for 600 kg/m³ and 0.50 N/mm² for 1200 kg/m³. The tensile strength was also influenced by the density of the mortar. For 0.15% of OPT it shows 0.20 N/mm² for 600 kg/m³ and 0.76 N/mm² for 1200 kg/m³. Other than that, for 0.30% of OPT it shows 0.20 N/mm² for 600 kg/m³ and 0.80 N/mm² for 1200 kg/m³. Finally, for 0.60% of OPT it shows 0.18 N/mm² for 600 kg/m³ density and 0.71 N/mm² for 1200 kg/m³ density.

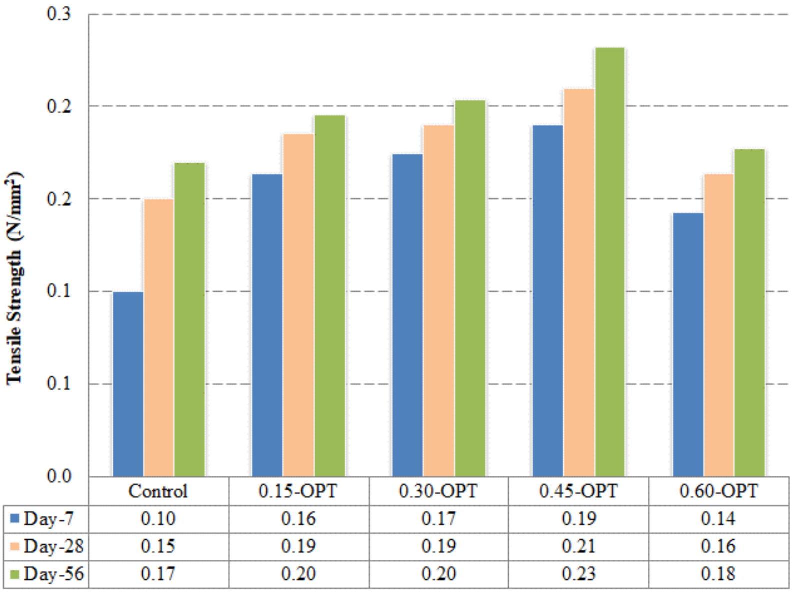


Fig. 17 - Tensile strength result of 600 kg/m³ density

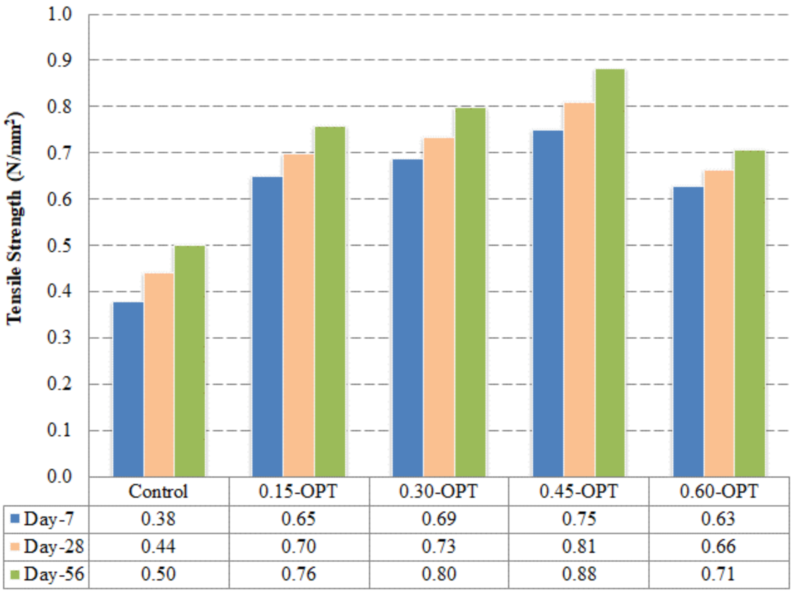
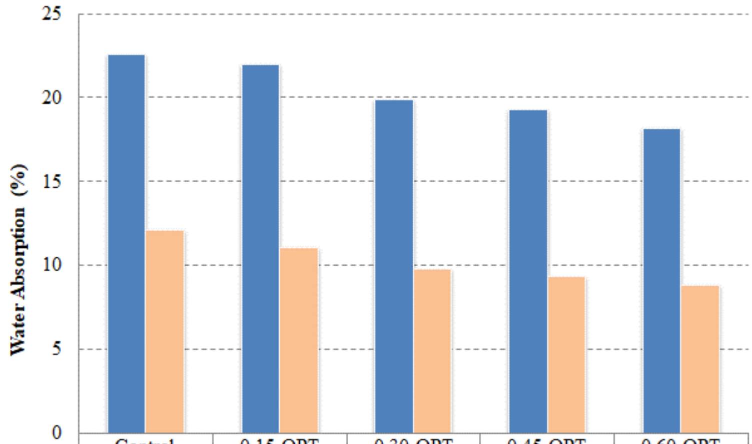


Fig. 18 - Tensile strength result of 1200 kg/m³ density

3.4 Water Absorption

Fig. 19 shows that the increase of OPT fibre will reduce the water absorption in the specimen of lightweight FC. The OPT fibre at 0.15% absorbs water higher compared to other OPT percentages, namely 21.9% for 600 kg/m³ and 11.0% for 1200 kg/m³. This is because the small pore size and volume will prevent water from infiltrating the specimen. The control specimens were 22.6% for 600 kg/m³ and 12.1% for 1200 kg/m³, which showed the highest result since it absorbs water. For the 0.30% of OPT it shows 19.9% for 600 kg/m³ and 9.8% for 1200 kg/m³, and for 0.45% of OPT it shows 19.3% for 600 kg/m³ and 9.3% for 1200 kg/m³. Lastly, for 0.60% of OPT it shows 18.1% for 600 kg/m³ and 8.8% for 1200 kg/m³. An increment of OPT percentages will reduce the water absorption of FC.

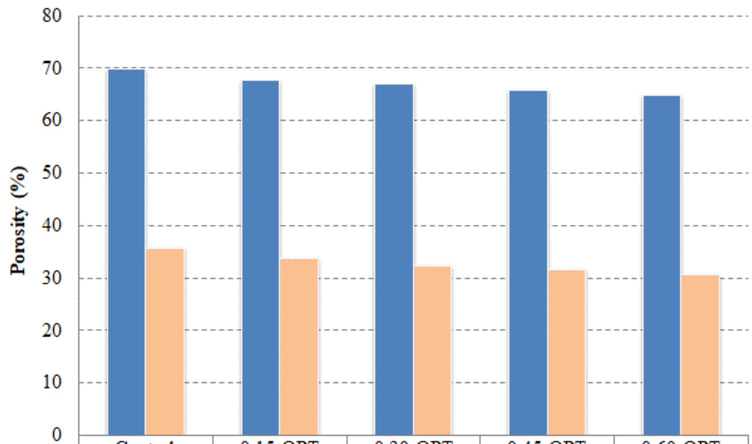


	Control	0.15-OPT	0.30-OPT	0.45-OPT	0.60-OPT
600kg/m3	22.6	21.9	19.9	19.3	18.1
1200kg/m3	12.1	11.0	9.8	9.3	8.8

Fig. 19 - The water absorption capacity of FC with different percentages of OPT fibre of both densities

3.5 Porosity

Fig. 20 shows the porosity result for 600 kg/m³ and 1200 kg/m³ densities of FC with different percentages of OPT fibre. The OPT fibre at 0.15% absorbs water higher compared to other percentages of OPT; 67.8% for 600 kg/m³ and 33.6% for 1200 kg/m³. The result shows that the increase of OPT will decrease porosity. This is because the small pore size and volume will prevent water from infiltrating the specimen. The control specimen was 69.7% for 600 kg/m³ and 35.5% for 1200 kg/m³, which shows the highest result since it absorbs water. Next, for the 0.30% of OPT it shows 66.9% for 600 kg/m³ and 32.2% for 1200 kg/m³. In addition, for 0.45% of OPT it shows 65.7% for 600 kg/m³ and 31.7% for 1200 kg/m³. Lastly, for 0.60% of OPT it shows 64.8% for 600 kg/m³ and 30.6% for 1200 kg/m³. The result in this experiment shows that the increment of OPT percentages reduces the porosity of FC.



	Control	0.15-OPT	0.30-OPT	0.45-OPT	0.60-OPT
600kg/m3	69.7	67.802	66.8885	65.7	64.8
1200kg/m3	35.5	33.598	32.314	31.7	30.6

Fig. 20 - The porosity of FC with different percentages of OPT fibre of both densities

3.6 Drying Shrinkage

Figures 21 and 22 show that drying shrinkage for all specimens are high from an early age until 30 days and then continues to increase. The addition of OPT causes the drying shrinkage of the specimen to increase. The 0.45% OPT fibre leads to a better result of drying shrinkage for both densities because it drastically increases. The density of 600 kg/m³ causes more general shrinkage than 1200 kg/m³, given the higher amount of foam content used in the mix. OPT reacts as an aggregate that gives the compact composition of the microstructure, which lessens and decreases the size and measures of the pores, thus improving the drying shrinkage (Fu *et al*., 2020). The highest value is for the control specimen. Notably, the highest value of drying shrinkage is not good for concrete since it can cause cracks in the future.

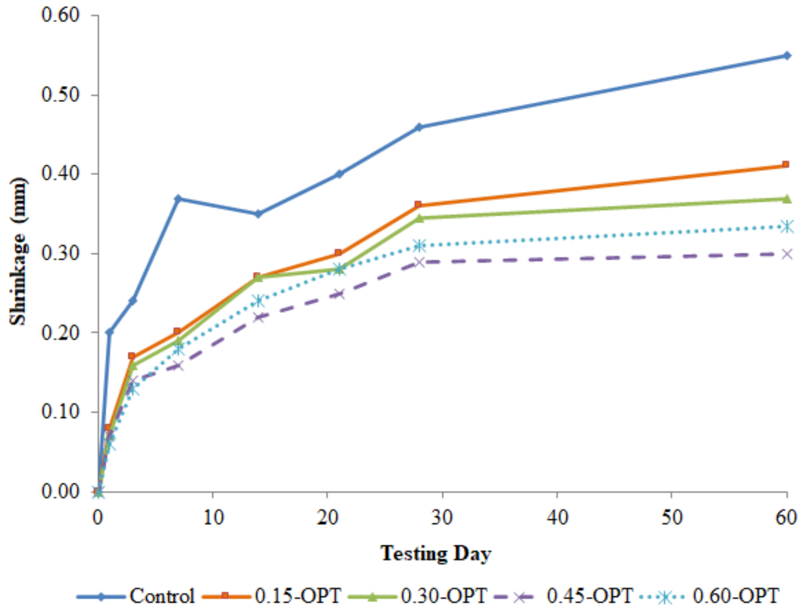


Fig 21 - Drying shrinkage result with different percentage of OPT fibre for 600 kg/m^3 density

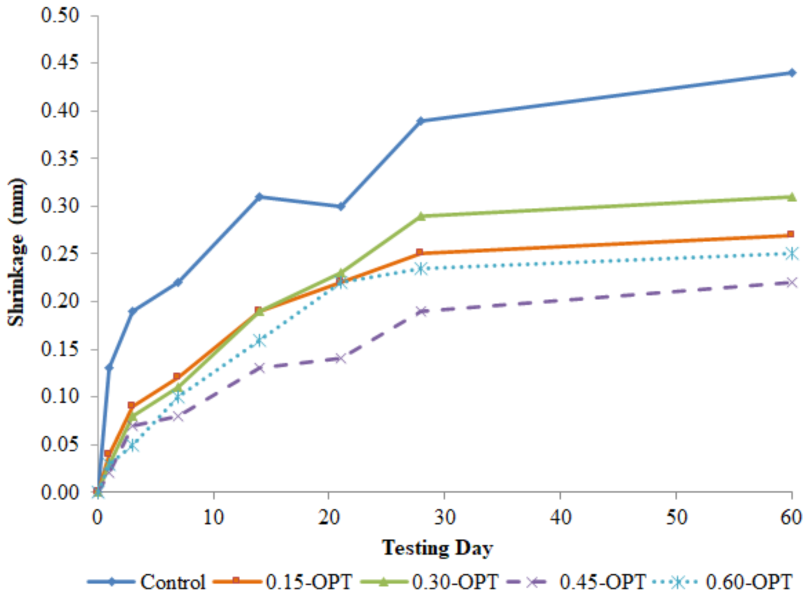


Fig. 22 - Drying shrinkage result with different percentage of OPT fibre for 1200 kg/m^3 density

3.7 Ultrasonic Pulse Velocity (UPV)

Fig. 23 shows the UPV result of 600 kg/m³ and 1200 kg/m³ densities of FC with different percentages of OPT fibre. The UPV method is completely harmless and is suitable for assessing the quality of concrete. This method can be used to detect internal cracks and other defects and concrete changes such as deterioration in an aggressive chemical environment, freezing and dilution. From the graph below, we can conclude that the concrete does not contain large voids or cracks, which would no doubt affect its structural integrity. The 0.45% OPF volume fraction contributed to the highest result of UPV. Therefore, the UPV is important to assess the presence of large voids in the interface zone and, finally, to check the OPT's quality and strength. The lowest value of UPV was for the control specimen. This method allows for calculating the strength of concrete and for concrete test specimens.

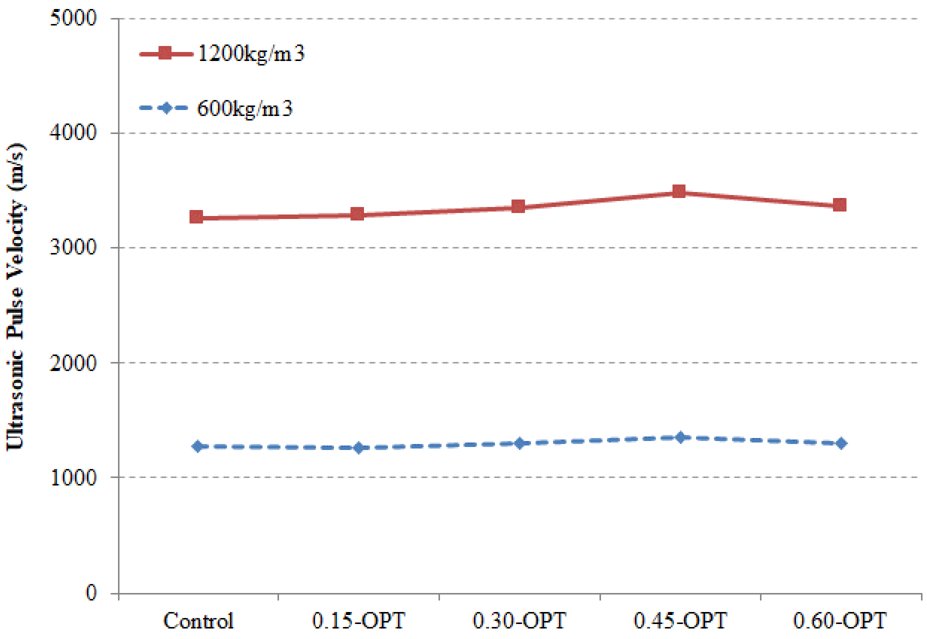


Fig. 23 - Ultrasonic pulse velocity (UPV) of FC with different percentages of OPT fibre of both densities

3.8 Scanning Electron Microscope (SEM) Analysis

The microstructure analysis was undertaken via Scanning Electron Microscope (SEM) observation. The rougher OPT surface was shown to be beneficial for fibre and cement matrix interfacial, as shown in Fig. 24. The rougher surface facilitates fibre and cement matrix mechanical interlocking. On the other hand, Fig. 25 illustrates the OPT external layer morphology.

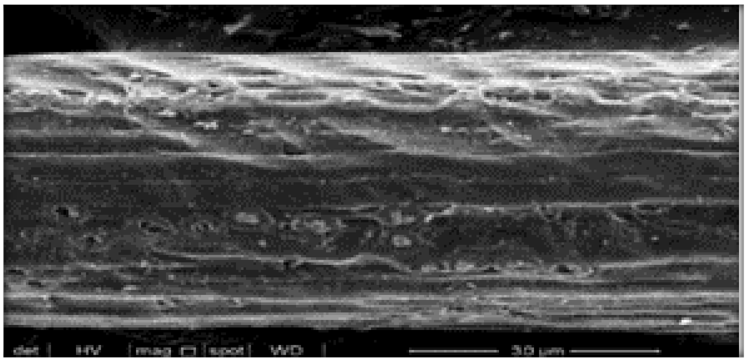


Fig. 24 - OPT fibre morphology

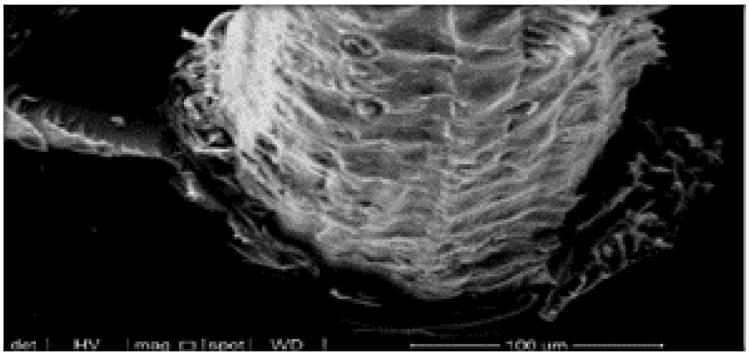


Fig. 25 - External layer of OPT fibre

Next, Fig. 26 shows the texture of OPT before testing was smooth in the cement matrix. After testing, many cavities existed at the cement surface, indicating OPF fibre pull-out failure under compression, as shown in Figure 27. OPF also experienced breakage and debonding from the cement matrix. The signs of OPT breakage from the cement matrix are evident when loaded under flexural, as shown in Fig. 28, and residues from the fibre surface after the debonding, presented in Fig. 29.

Fig. 26 - The texture of OPT fibre before the compression test

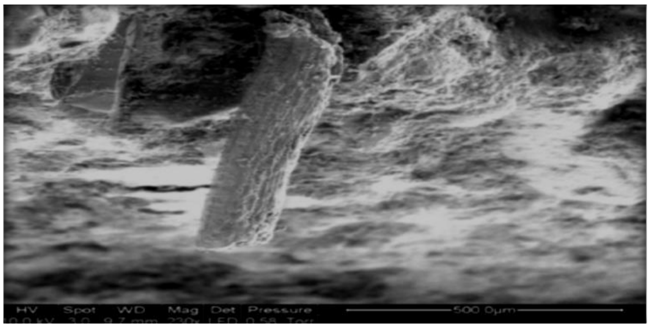


Fig. 27 - OPF fibre pull-out failure after the compression test

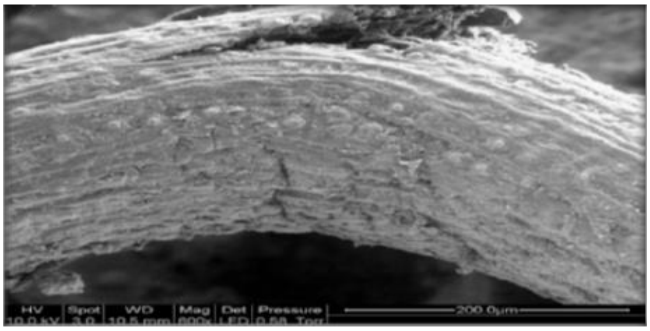


Fig. 28 - Breakage of OPT fibre under flexural loading

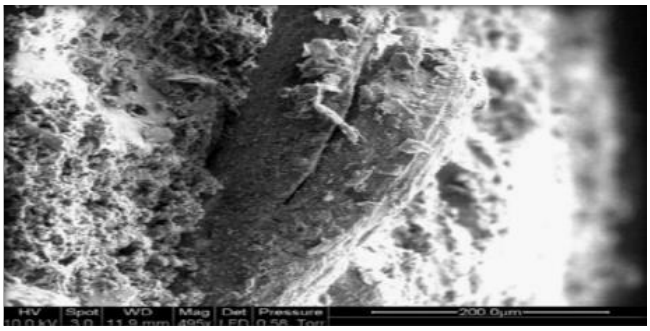


Fig. 29 - Surface debonding between OPT fibre and cement matrix

4.0 Conclusion

Overall, the strength of the FC in this research improved with the addition of OPT fibre. However, the different percentages of OPT fibre added to the FC gave a different result on the mechanical and durability properties of FC. The increment of OPT fibre volume fraction reduced the water absorption capacity and porosity of the FC. In general, 0.45% of OPT fibre volume fraction in FC offered outstanding drying shrinkage, compressive strength and flexural strength compared to other percentages used. It should be highlighted that the outside part of OPT fibre is rough, allowing for the spread of nodes and irregular stripes. Additionally, the OPT cell wall's outside surface was covered with lignin, wax, and oil. Fibre-matrix interface bonding, which is regarded as a coarser surface, is helpful given its surface roughness. Accordingly, it empowers the OPT fibre, and matrix mechanical interlocking, thereby improving both the durability and mechanical properties of the FC.

Acknowledgement

The authors would like to thanks the Universiti Sains Malaysia for giving the opportunity to conduct this research.

References

Al Rim. K, Ledhem. A, Douzane. O, Dheilly. R. M, Queneudec. M, (1999). Influence of The Wood on The Thermal and Mechanical Performances of Clay-Cement-Wood Composites. Cement and Concrete Composites, 21, pp. 269-276.

ASTM C293 / C293M-16 (2016). Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading), ASTM International, West Conshohocken, PA

ASTM C496 / C496M-17 (2017). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA

ASTM C878 / C878M-14a (2014). Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete, ASTM International, West Conshohocken, PA

BS 12 (1996). Specification for Portland cement. British Standards Institution: 1-18

BS 12390-3 (2011). Testing hardened concrete. Compressive strength of test specimens. British Standard Institution: 1-24

BS 12504-4 (2004). Testing concrete. Determination of ultrasonic pulse velocity. British Standard Institution: 1-18

BS 1881-122 (1983). Testing concrete. Method for determination of water absorption. British Standards Institution: 1-14

BS 882 (1992). Specification for aggregates from natural sources for concrete. British Standards Institution: 1-14

Elrahman, M. A, El Madawy, M. E., Chung, S. Y., Sikora, P., Stephan, D. (2019). Preparation and characterization of ultra-lightweight foamed concrete incorporating lightweight aggregates. Applied Sciences (Switzerland), 9(7): 1-12

Fu Y, Wang X, Wang L, Li Y. (2020). Foam Concrete: A State-of-the-Art and State-of-the-art Practice Review. Advances in Materials Science and Engineering, 6153602, 1-25

Hamad, A. J. (2014). Materials, production, properties and application of aerated lightweight concrete. International journal of materials science and engineering, 2(2), 152-157.

Jalal, M. D., Tanveer, A., Jagdeesh, K., Ahmed, F. (2017). Foam concrete. International Journal of Civil Engineering Research, 8(1): 1-14 Hedjazi S. (2019). Compressive Strength of Lightweight Concrete. In Intech Open:1-18

Jhatial, A. A., G. W. Inn, N. Mohamad, U. J. Alengaram, K. H Mo, R. Abdullah. (2017). Influence of polypropylene fibres on the tensile strength and thermal properties of various densities of foamed concrete. IOP Conference Series: Materials Science and Engineering 271 (1), 012058

Kamaruddin, S., Goh, W. I., Jhatial, A. A., & Lakhiar, M. T. (2018). Chemical and Fresh State Properties of Foamed Concrete Incorporating Palm Oil Fuel Ash and Eggshell Ash as Cement Replacement. International Journal of Engineering & Technology, 7(4.30), 350

Kim. Y, Jiong. H, Jae. L, and Heeyou. B, (2010). "Mechanical Properties of Fiber Reinforced Lightweight Concrete Containing Surfactant", Advances in Civil Engineering, 10, 1-9.

Lim, S. K., Tan, C. S., Lim, O. Y., & Lee, Y. L. (2013). Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler.

Mahzabin M. S., Hock, L. J., Hossain, M. S., Kang, L. S. (2018). The influence of addition of treated kenaf fibre in the production and properties of fibre reinforced foamed composite. Construction and Building Materials, 178: 518-528

Majid, A., Anthony L., Hou, S., Nawawi, C. (2012). Mechanical and dynamic properties of coconut fibre reinforced concrete. Construction and Building Materials, 30, pp. 814-825.

Memon I. A., Jhatial, A. A., Sohu S., Lakhiar M. T., Hussain Z. (2018). Influence of Fibre Length on the Behaviour of Polypropylene Fibre Reinforced Cement Concrete. Civil Engineering Journal, 4(9): 2124-2131.

Mohammad Hosseini, H., Abdul Awal, A. S. M., & Sam, A. R. M. (2016). Mechanical and thermal properties of prepacked aggregate concrete incorporating palm oil fuel ash. Sadhana, 41(10), 1235-1244.100

Momeen, M., Islam, U., Mo, K. H., & Alengaram, U. J. (2016). Durability properties of sustainable concrete containing high volume palm oil waste materials. Journal of Cleaner Production, 137, 167-177.

Moon, A. S., Varghese, V., Waghmare, S. S. (2015). Foam Concrete as A Green Building Material. International Journal for Research in Emerging Science and Technology, 2(9): 25-32.

Müllera, H. S., Breinera, R., Moffatta, J. S., & Haista, M. (2014). Design and properties of sustainable concrete. Procedia Engineering, 95(Scescm), 290-304

Munir, A., Abdullah, Huzaim, Sofyan, Irfandi, & Safwan. (2015). Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material. Procedia Engineering, 125, 739-746.

Muthusamy, K. & Zamri, N.A (2016). Mechanical Properties of Oil Palm Shell Lightweight Aggregate Concrete Containing Palm Oil Fuel Ash as Partial Cement Replacement. KSCE Journal of Civil Engineering, 20(4), 1473-1481.

Mydin, M. A. O., Musa, M., Ghani, A. N. A. (2016). Fiber glass strip laminates strengthened lightweight foamed concrete: Performance index, failure modes and microscopy analysis. AIP Conference Proceedings, 2018, 020111

Othuman Mydin, M. A., Noordin, N. M., Utaberta, N., Mohd Yunos, M. Y., Segeranazan, S. (2016). Physical properties of foamed concrete incorporating coconut fibre. Jurnal Teknologi, 78(5), 99-105

Ramamurthy, K., Kunhanandan Nambiar, E. K., & Indu Siva Ranjani, G. (2009). A classification of studies on properties of foam concrete. Cement and Concrete Composites, 31(6), 388-396.

Sari, K. A. M., Sani, A. R. M. (2017). Applications of Foamed Lightweight Concrete. MATEC Web of Conferences, 97: 1-5.

Serri, E., Othuman Mydin, M. A., Suleiman, M. Z. (2014). Thermal properties of Oil Palm Shell lightweight concrete with different mix designs. Jurnal Teknologi, 70(1), 155-159

Suhendro, B. (2014). Toward green concrete for better sustainable environment. Procedia Engineering, 95(Scescm), 305-320.

Sumit, C., Sarada, P. K, Aparna R, Ratan K.B, Basudam A, Majumder S.B, (2013). Improvement of the mechanical properties of jute fiber reinforced cement mortar: A statistical approach. Construction and Building Materials, 38, pp. 776-784.

Tangchirapat, W., & Jaturapitakkul, C. (2010). Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash. Cement and Concrete Composites, 32(10), 767-774.

Thakrele, M. H. (2014). Experimental study on foam concrete. International journal of Civil Structure Environment Infrastructure Engineering Research and development (IJCSEIERD), 4(1-2014), 145-158

Thakrele, M. H. (2014). Experimental study on foam concrete. International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development, 4(1), 145-158