



INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES



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ISSN: 2222-6990

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To Link this Article: <http://dx.doi.org/10.6007/IJARBSS/v12-i1/11926>

DOI:10.6007/IJARBSS/v12-i1/11926

Received: 12 November 2021, **Revised:** 15 December 2021, **Accepted:** 28 December 2021

Published Online: 11 January 2022

In-Text Citation: (Mydin, 2022)

To Cite this Article: Mydin, M. A. O. (2022). Mechanical Properties of Foamed Concrete with the Addition of Oil Palm Trunk Fibre. *International Journal of Academic Research in Business and Social Sciences*, 12(1), 253–264.

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Vol. 12, No. 1, 2022, Pg. 253 – 264

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ISSN: 2222-6990

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

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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 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, mechanical properties were examined. The results showed that the addition of OPT fibre in FC improved the compressive strength, flexural strength, tensile strength 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/m^3 , 0.45% volume fraction of OPT was the optimum percentage.

Keywords: Foamed Concrete, Compressive Strength, Flexural, Tensile, Tensile Properties

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 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 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). 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.

Material Constituents, Mix Proportion and Tests

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.

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. 1. Fine sand was used with a size of 1.18 mm to improve the FC flow characteristics and stability.

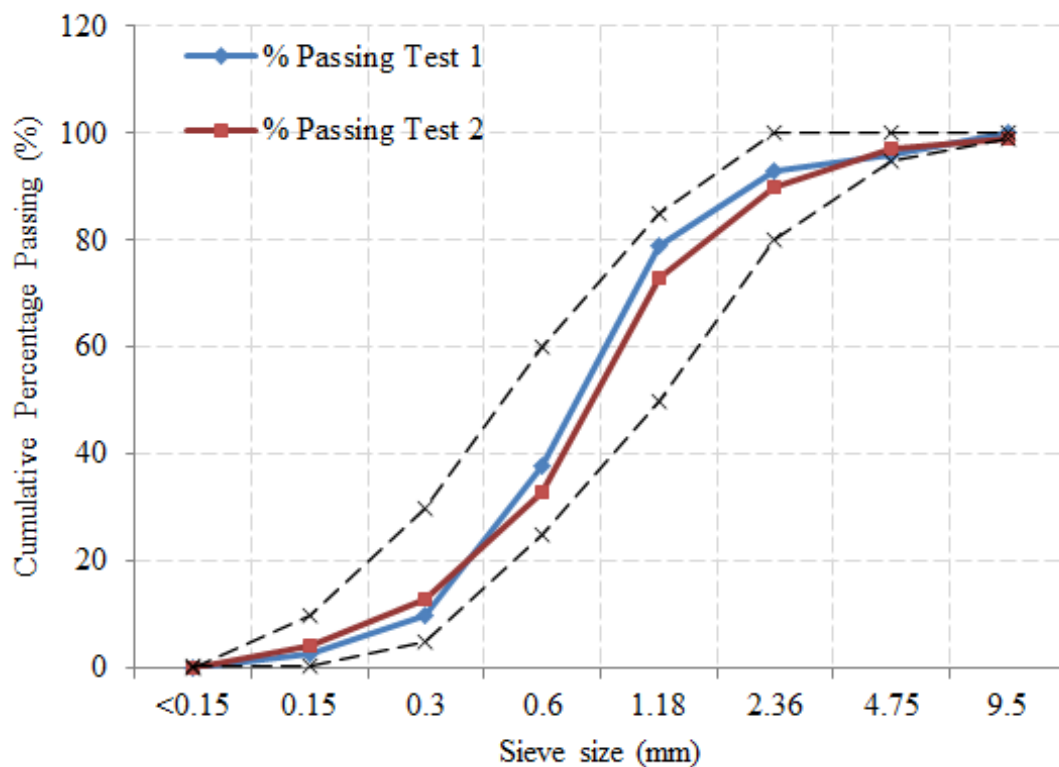


Fig. 1 – Sieve analysis result of fine sand

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.

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. 2). The volume fraction of the fibre used was 0.15%, 0.30%, 0.45%, 0.60% and 0% of the total weight mix volume. Table 1 and Table 2

show the chemical composition and physical properties of OPT fibre used in this study respectively.



Fig. 2 - Oil palm trunk fibre was dried for two days

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 (°)	42

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

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. 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.

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. 3), 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. 4). The tensile test was conducted on a 100 mm diameter x 200 mm height cylinder, according to ASTM C496 (ASTM C496, 2017) (see Fig. 5).

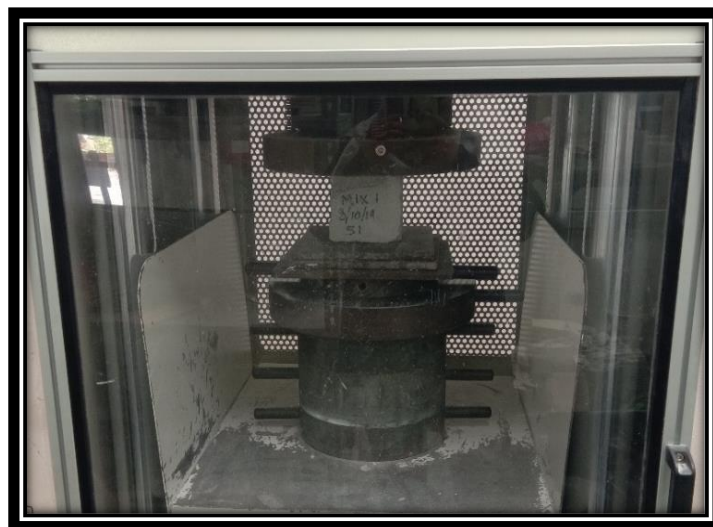
**Fig. 3 - Compression Test according to BS EN 12390: Part 3**



Fig. 4 - The flexural test was performed according to ASTM C293

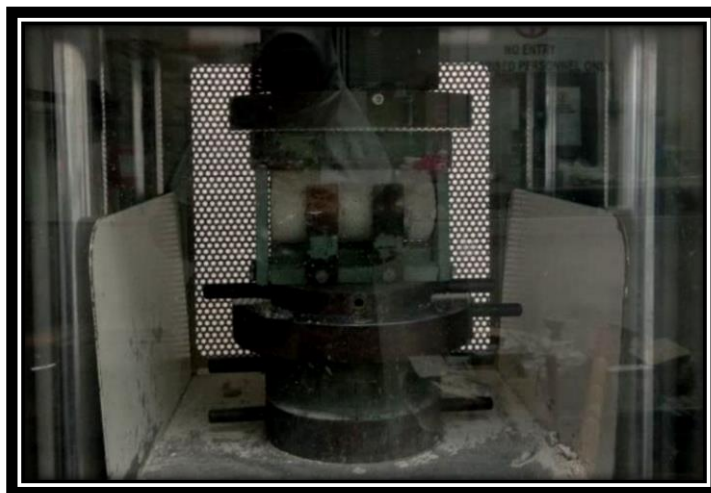


Fig. 5 - The splitting tensile test was carried out according to ASTM C-496

Results and Discussion

Compressive Strength

Figures 6 and 7 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/m³ 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 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, 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.

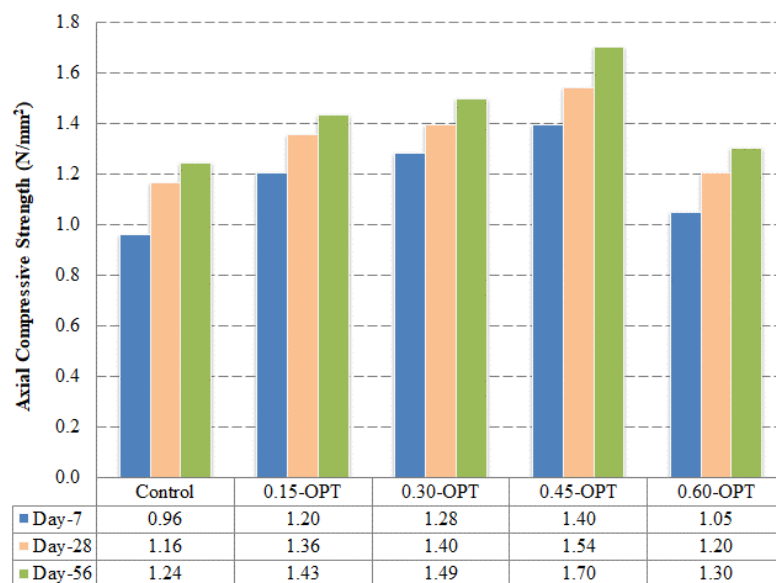


Fig. 6 - Compressive strength result of 600 kg/m³ density

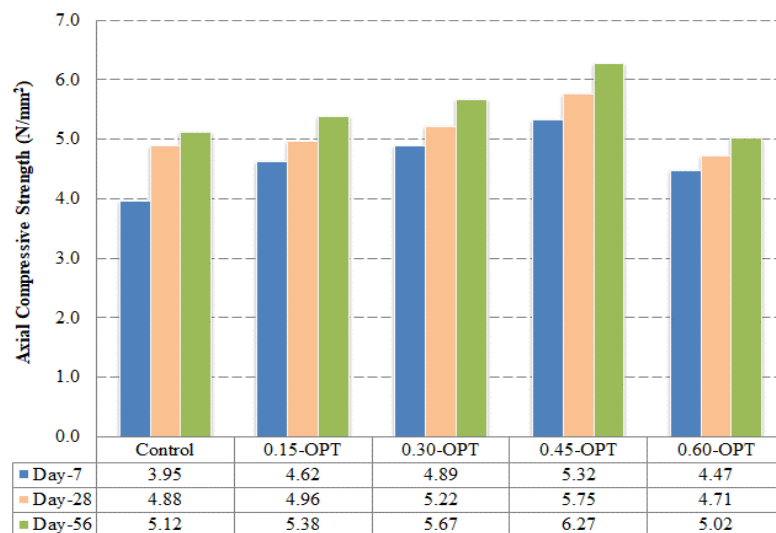


Fig. 7 - Compressive strength result of 1200 kg/m³ density

Flexural Strength

Figures 8 and 9 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 addition of OPT fibre as reinforcement for the concrete.



Fig. 8 - Flexural strength result of 600 kg/m³ density

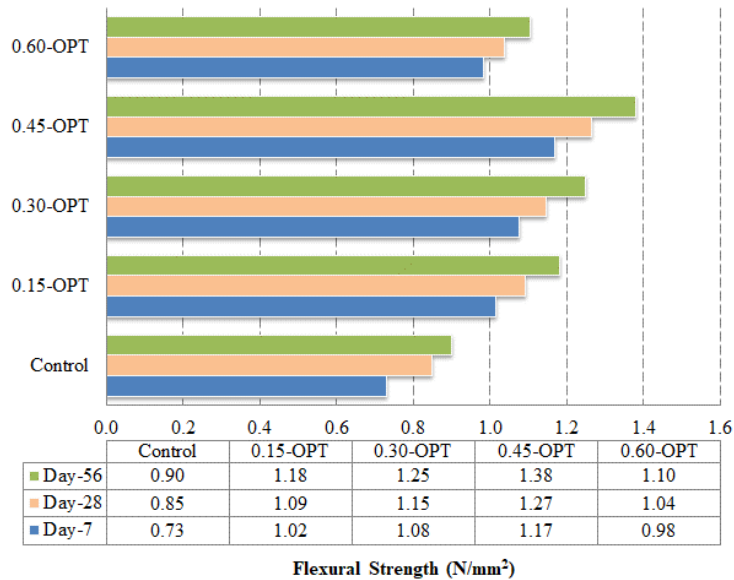


Fig. 9 - Flexural strength result of 1200 kg/m³ density

Tensile Strength

Figures 10 and 11 show the result of splitting tensile strength of lightweight FC with the additive of OPT fibre for 600 kg/m³ and 1200 kg/m³. 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. 10 - Tensile strength result of 600 kg/m³ density

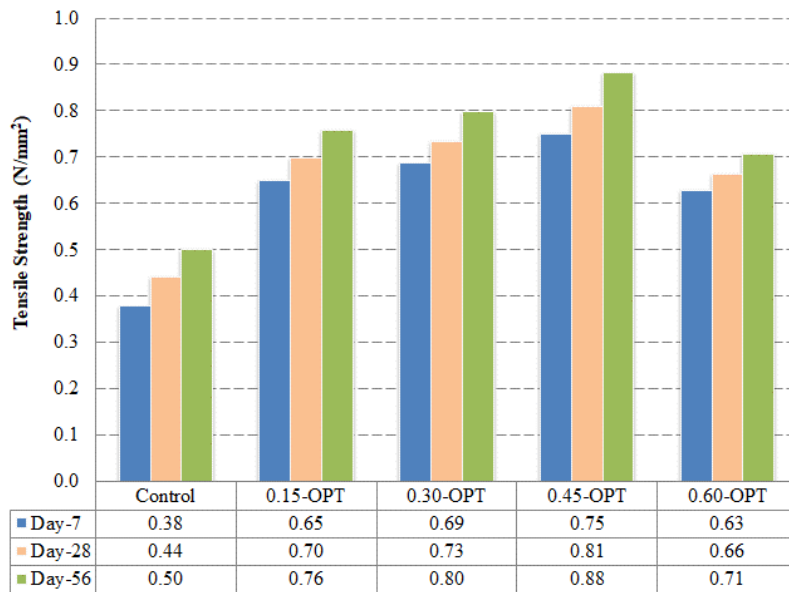


Fig. 11 - Tensile strength result of 1200 kg/m³ density

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 properties of 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 mechanical properties of the FC. The results of this fundamental study could pave the way to produce high performance FC with the addition of biomass waste from oil palm. Output from this research would give a better insight of the potential utilization of fibre from oil palm in FC.

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