:: IJEBD ::
(International Journal of Entrepreneurship and Business Development)
Volume 05 Number 05 September 2022

ISSN : 2597-4785 (ONLINE)
ISSN : 2597-4750 (PRINTED)

Effects of the Partial Replacements of Oil Palm Boiler Clinker (OPBC) on the Density and Compressive Strength of Concrete

Muhammad Lutfi Othman[1,2], Noor Nabilah Binti Sarbini[3], Redzuan Abdullah[4], Mohamad Salleh Bin Yassin[4]

PhD Student, University Teknologi Malaysia[1]
Lecturer, Politeknik Port Dickson, Malaysia[2]
Senior Lecturer, University Teknologi Malaysia[3]
Assistant Professor, University Teknologi Malaysia[4]
lutfi@polipd.edu.my

ABSTRACT

Purpose: Oil Palm Boiler Clinker (OPBC) is a promising waste material that can be deployed toward sustainable development. Researchers have been looking into the potential of industrial wasteand by-products to provide an alternative to natural stone aggregates in concrete production. This study aims to determine an OPBC concrete mix eligible for lightweight reinforced precastconcrete products according to BS EN 13369:2013.

Design/methodology/approach: The concrete mix design is determined via the trial mix method, where percentages of OPBC are varied as partial replacements in the control mix. Raw OPBC is collected from a local palm oil mill in Johor, Malaysia and is processed to be implemented in the concrete mix. Three 100mm cube samples of nine OPBC mixes and one control mix are tested and weighed on day 1, day 7, and day 28 to determine their cube compressive strength and density to BS EN 12390-3:2009. The mix that fulfils the requirements is the mix with 90% coarse clinker and 90% fine clinker, cured by the method ofair curing, which achieved a cube compressive strength of 38.66N/mm^2 and density of1920kg/m^3.

Findings: In conclusion, the results show that OPBC concrete is a green alternative to standard concrete that does not differ significantly in terms of strength while offering a densityreduction of as much as 16%.

Originality/value: This paper is original

Paper type: Research paper

Keywords: *Finite Element, Four-Point Flexural Test, Green Concrete, Lightweight Precast Slab, Oil-Palm-Boiler-Clinker Concrete, Semi-Circular Arch Hollow Slab, Sustainable*

Received : July 29th
Revised : July 29th
Published : September 30th

I. INTRODUCTION

A building made with lighter materials possesses benefits, including the reduced size of structural and supporting members, easier moving, and improved seismic load resistance (Babu & Rex, 2019; Ng et al., 2007; Yardim et al., 2013). One of the many ways of reducing the mass of dead weight of structures is by adopting lightweight concrete (Sajedi & Shafigh, 2012). The production of lightweight concrete usually involves including air and void in the concrete. In this light, the most popular method to produce lightweight concrete is substituting conventional mineral aggregates with lighter ones (Shetty, 2008).

Oil Palm Boiler Clinker (OPBC) is a promising waste material that can be deployed in the orientation toward sustainable development as researchers have been looking into the potential of industrial waste and by-products to provide an alternative to the natural stone aggregates in concrete production (Aslam et al., 2016; Ismail et al., 2013; Mo et al., 2015; Shi et al., 2015). OPBC is a lightweight porous aggregate, well- graded material with a size range usable in both fine and coarse aggregate. Researchers have incorporated OPBC into

ISSN : 2597-4785 (ONLINE)
ISSN : 2597-4750 (PRINTED)

concrete mixtures to produce lightweight structural concrete with a density between 1440 to 2020 kg/m3 and 28-day compressive strength in the range of 17 to 42 MPa (Aslam et al., 2017). In a study by Ahmad where coarse and fine OPBC replaces the proportions of coarse and fine normal aggregates in a concrete mix, Ahmad finds that the compressive strength of the OPBC concrete decreases by 30.86% while at the same time also resulting in a reduction of as much as 35.14% in density, in comparison to regular concrete (Ahmad et al., 2007). Palm-oil industry biomass wastes such as palm shells, palm fibre, and palm kernels, utilized as a fuel substitute in palm oil boilers when no longer combustible, forms the OPBC (Shafigh et al., 2014; V.I et al., 2014). Tropical countries such as Malaysia, Indonesia, and Thailand contribute close to 90% of the world's total palm oil production, which indicates that the availability of the OPBC is also as much (Aslam et al., 2016). Therefore, this paper aims to compare the effects of partially replacing the proportions of the natural aggregates with OPBC aggregates on the strength and density of concrete. At the same time, this study also aims to determine the best OPBC concrete mix that can fulfil the minimum requirement for lightweight reinforced precast concrete products according to BS EN 13369: 2013.

II. METHODOLOGY

The main aim of the experimental program is to determine an OPBC concrete mix that is eligible for lightweight reinforced precast concrete products according to BS EN 13369:2013. The OPBC concrete mix is produced by partially replacing the portions of coarseand fine aggregates of a standard concrete mix with coarse and fine OPBC aggregates. The concrete mix design is determined via the trial mix method, where percentages of OPBC are varied as partial replacements in the control mix. The control concrete mix is designed for a characteristic strength of 40N/mm^2 at 28 days by adopting the method proposed by Building Research Establishment or the DOE method (Teychenné et al., 1997). Three 100mm x 100mm x 100mm cube samples of various OPBC mixes are tested and weighed on the day of demolding (day 1), day7, and day 28 to determine their cube compressive strength, $f_{ck,cube}$, and density, respectively,conforming to BS EN 12390-3:2009 (British Standards Institution, 2009a). Figure 1 illustrates the compressive test and weighing process conducted on the samples.

Figure 1. (a) Compressive test on samples, (b) weighing of samples

A. Material

1. Cement

The ordinary Portland cement CEM I 42.5 certified to MS EN 197-1 was adopted in this study as it contains an adequate amount of C3S (Tricalcium Silicate) proportion which was imperative to the contribution of strength in concrete (Nawy, 1997). The typical specific gravity value of cement is taken as 3.15 (Mortazavi & Majlessi, 2012).

2. Oil-palm-boiler-clinker (OPBC) Concrete

The raw OPBC is collected from Taib Andak palm oil mill in the Kulai district of Johor, Malaysia, as depicted in Figure 2 and is then prepared per the flow chart illustrated in Figure 3. The material's preparations conform to Clause 5.1.2 in ASTM C330 on lightweight aggregate for structural concrete grading requirements (ASTM C330, 2017). The raw material, as shown in Figure 4 (a), which closely resembled a rough-surfaced porous rock in the size of approximately 100mm to 200mm, is first crushed with the utilization of the Los Angeles Abrasion Testing Machine (Figure 5 (a)) at a setting of 1000 rotations per cycle. The machine's drum

ISSN : 2597-4785 (ONLINE)
ISSN : 2597-4750 (PRINTED)

rotates while the four ball bearings included with the raw OPBC act as a mechanism to crush the raw OPBC into smaller pieces. Figure 5 (b) illustrates the ball bearing used in the machine. Afterwards, if the 9.5mm sieve retains the crushed OPBC during the filtering process, the product is then further crushed using the stone crusher machine, as depicted in Figure 5 (c), to get a smaller aggregate size than 9.5mm.

Figure 2. (a) Raw OPBC in the Felda Taib Andak Palm Oil Mill's dumpsite, (b) Thedischarge area that produced fresh damp OPBC, (c) & (d) Raw OPBC collected and transported to the lab

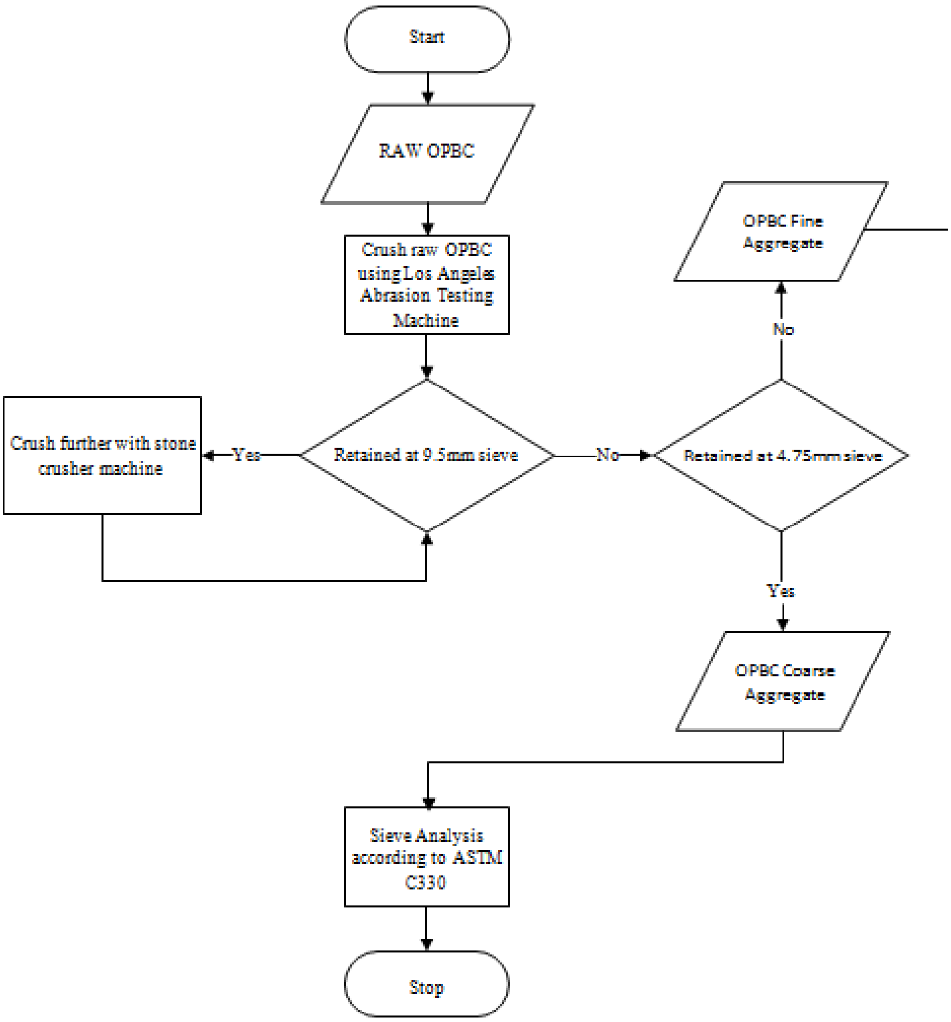

Figure 3. Flow-chart of raw OPBC preparation process

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ISSN : 2597-4750 (PRINTED)

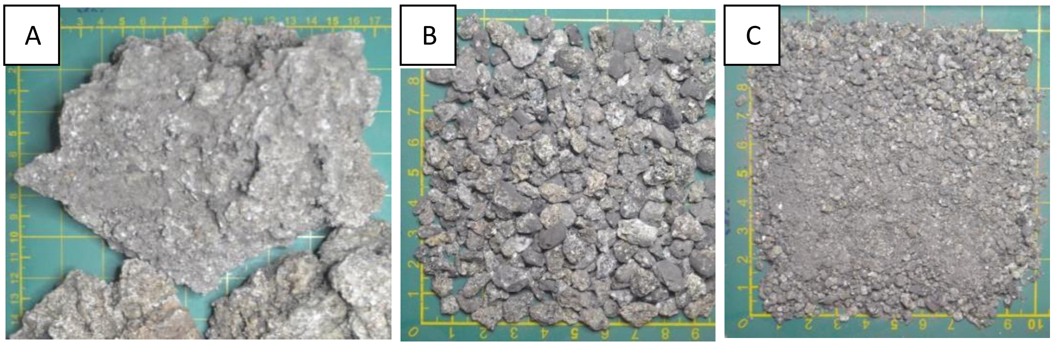

Figure 4. (a) Raw OPBC, (b) Coarse OPBC, (c) Fine OPBC

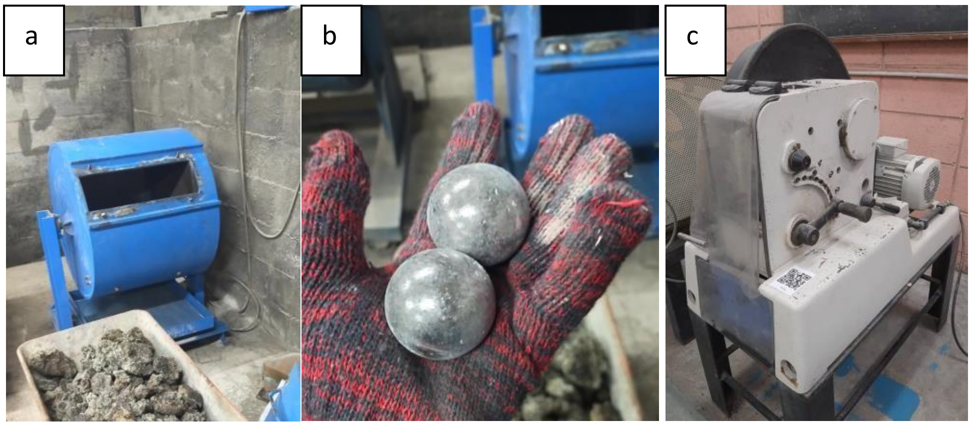

Figure 5. (a) Los Angeles Abrasion Testing Machine, (b) ball bearings, (c) stone crusher machine

Meanwhile, the crushed OPBC that passed the 9.5mm sieve but retained at the 4.75mm sieve is cast aside and categorized as coarse OPBC, as shown in Figure 2.4 (b). Subsequently, the crushed OPBC that passes through the 4.75mm sieve is tagged as a fine OPBC, as illustrated in Figure 2.4 (c). Finally, the sieve analysis is performed on both the coarse and the fine OPBC to conform to the grading requirements of ASTM C330. Figure 2.6 and Table 2.2 represent the sieve analysis and material properties of the normal aggregates and the OPBC aggregates to be implemented in casting the OPBC concrete precast slab specimens in this research.

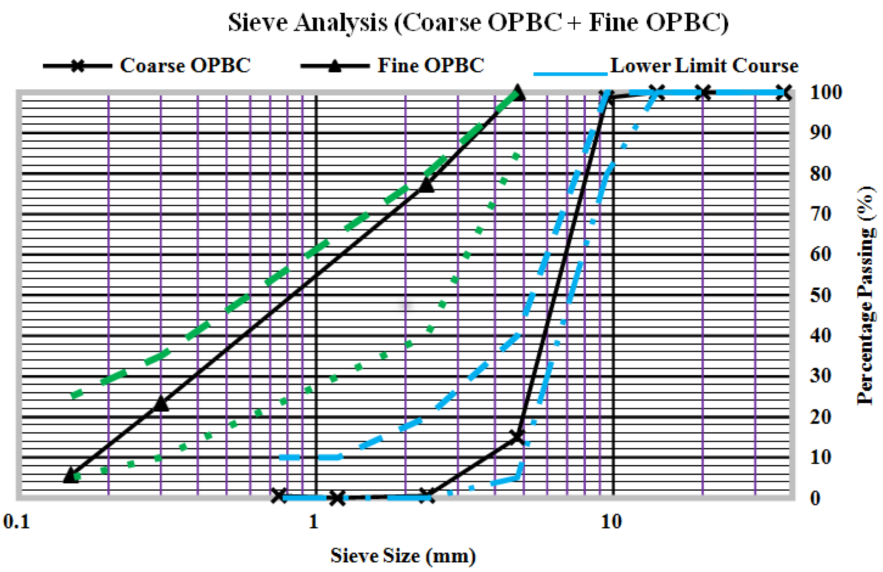

Figure 6. Sieve analysis of OPBC implemented in the preparation of OPC slab Specimen

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B. Mix design

As a starting point, the proportions of the concrete were designed according to the Building Research Establishment (BRE) mix design method for standard concrete before the proportions for coarse and fine aggregates were partially replaced with fine and coarse OPBC. The initial strength of the control concrete mix was designed for compressive strength of 40MPa (Teychenné et al., 1997). High compressive strength was selected due to the reductions of strength expectedto be caused by the introduction of lightweight aggregates in the mix. For the mix to be eligiblefor lightweight reinforced precast concrete products, it is required to achieve a minimum compressive strength of at least LC16/18 according to BS EN 13369:2013 (British Standards Institution, 2018). The aim was to find the best mix with the lowest density while simultaneously carrying a minimum 28- days cube compressive strength of at least 18MPa. The ratios of the mixes are shown in Table 1. Mix 1 is the control mix, where 0% of OPBC is adopted in the mix. Mix number 1 to 8 is cured inside a water tank, while mix 9 and 10 are cured by air curing. There are two sets of variables within mix 2 to 8. The first set consists of mixes 2, 3, 4 and 8, where the amount of CC is constant while the amount of FC varies. The second set includes mixes 5, 6, 7 and 8, where the amount of FC is constant while the amount of CC varies. The amount of OPBC coarse and fine aggregates to replace the portions of the normal coarse and fine aggregates is calculated using the absolute volume method based on values presented in Table 2. All the mixes are mixed by drum mixer based on the procedures mentioned by BS1881-125:2013 Methods for mixing and sampling fresh concrete in the laboratory (British Standards Institution, 2013a).

Table 1. OPBC Concrete mix ratio

Mixnum.	*Concrete mix*	*Normal Coarse Aggregate (kg/m^3)*	*Normal Fine Aggregate (kg/m^3)*	*OPBC Coarse Aggregate (kg/m^3)*	*OPBC Fine Aggregate (kg/m^3)*	*Cement (kg/m^3)*	*Water (kg/m^3)*	*W/C*
1	0% CC + 0% FC (Control)	594	1056	0	0	490	325	0.66
2	100%CC + 0%FC	0	1056	380.6	0	490	325	0.66
3	100%CC + 33%FC	0	707.52	380.6	279.52	490	325	0.66
4	100%CC + 67%FC	0	348.48	380.6	567.51	490	325	0.66
5	0%CC + 100%FC	594	0	0	847.04	490	325	0.66
6	33%CC + 100%FC	594	0	0	847.04	490	325	0.66
7	67%CC + 100%FC	594	0	0	847.04	490	325	0.66
8	100%CC + 100%FC	0	0	431..2	847.04	490	325	0.66
9	80%CC + 80%FC	118.8	211.2	344.96	677.63	490	325	0.66
10	90%CC + 90% FC	59.4	105.6	388.08	762.33	490	325	0.66

**CC = coarse clinker, FC = fine clinker*

ISSN : 2597-4785 (ONLINE)
ISSN : 2597-4750 (PRINTED)

Table 2. Specific gravity and water absorption of normal aggregates and OPBC aggregates

	Normal coarse aggregate	Normal fine aggregate	OPBC coarse aggregate	OPBC fine aggregate
Specific Gravity	2.7	2.6	1.96	2.09
Water absorption (%)	1.58	2.4	8.81	19.5

III. RESULTS AND DISCUSSION

The results compiled in Table 3. consists of the slump value, curing method, density at different ages, and the cube compressive strength on day 7 and 28. The slump of all the mixes is measured, conforming to the method stated in BS EN 12350-2 (British Standards Institution, 2009b). The slump values range from 80mm to 160mm.

Table 3. Density and cube compressive strength of OPBC concrete at 7 days and 28 days

Mix num.	Concrete mix	Slump	Curing Method	Density (kg/m^3)			Cube compressivestrength (N/mm^2)	
				Before curing	7 days curing	28 days curing	7 dayscuring	28 dayscuring
1	0% CC + 0% FC	100	watertank	2215	2260	2284	37.58	43.45
2	100%CC + 0%FC	80	water tank	2108	2145	2141	34.05	39.39
3	100%CC + 33%FC	160	water tank	2013	2050	2054	28.9	32.76
4	100%CC + 67%FC	110	water tank	2001	2041	2050	36.14	41.71
5	0%CC + 100%FC	110	water tank	2157	2198	2208	38.32	44.2
6	33%CC + 100%FC	140	water tank	2091	2138	2136	35.87	39.62
7	67%CC + 100%FC	130	water	1982	2028	2030	28.39	38.76

:: IJEBD ::
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ISSN : 2597-4785 (ONLINE)
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			tank					
8	*100%CC + 100%FC*	*90*	*watertank*	*1942*	*1973*	*2023*	*29.26*	*38.96*
9	*80%CC + 80%FC*	*110*	*air*	*2025*	*1997*	*1970*	*26.77*	*37.86*
10	*90%CC + 90% FC*	*100*	*air*	*1993*	*1956*	*1920*	*27.42*	*38.66*

A. Density

Concrete mix 1 to 8 cured in a water tank shows an increasing density value the more prolonged the curing period, as shown in Figure 3. The density escalation is caused by the water absorption of the concrete cubes, where the 100% OPBC mix shows the highest increase. On the other hand, concrete mix 9 and 10 that are cured by leaving them exposed in a room shows a decreasing pattern in density value. At 28 days, only mix 9 and 10 can be considered lightweight concrete, based on the definition of lightweight concrete in BS EN 206 (British Standards Institution, 2013b). At 28 days, mix one, the control mix, obtained the highest density, 2284kg/m^3. The second highest density is 2208kg/m^3, gained by mix 5 which consists of 0% CC and 100% FC. The third highest density is mix two, which contains 100% CC and 0% FC. On the other hand, the lowest density for mixes cured in a water tank is mix 8, which consists of 100% CC and 100% FC, with a density value close to a lightweight category, 2023kg/m^3.

Density of mix VS Curing age

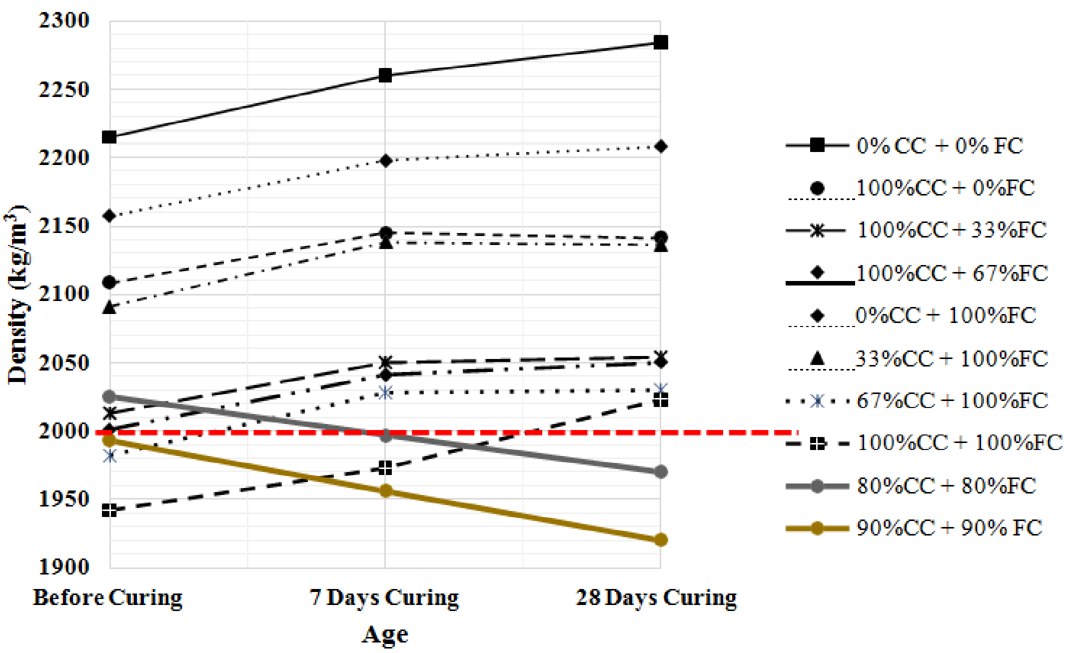
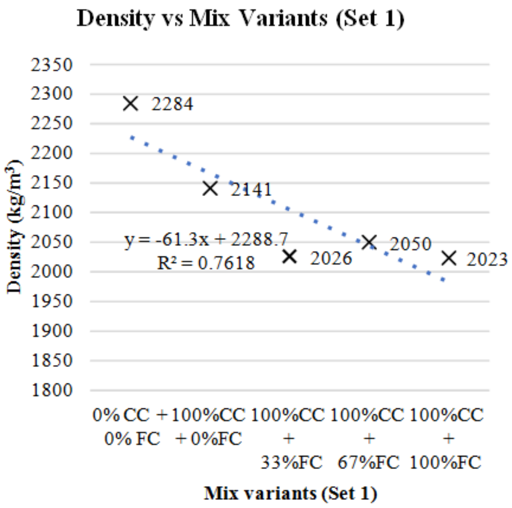


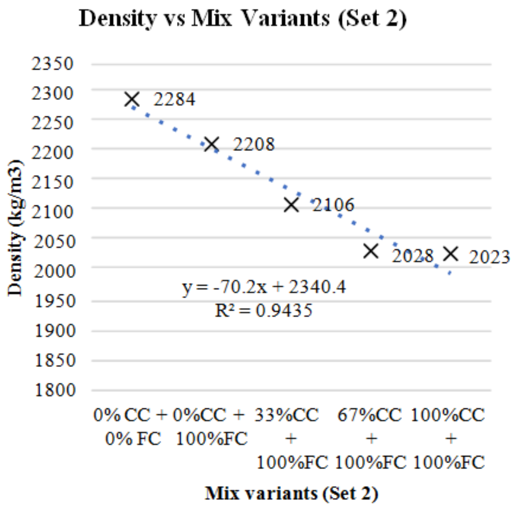
Figure 7. Density of mixes by curing age

Figure 7 illustrates the density against the mix variants. Set 1 mix variants fix the amount of CC to 100% and vary the percentages of FC to 0%, 33%, 67% and 100%. Meanwhile, the amount of FC in set 2 mix variants is at a constant of 100% but varies in the quantity of CC. The percentages of CC implemented in set 2 are 0%, 33%, 67% and 100%. The effects of the mix variations are shown in Figure 8 (a) and (b), where both of the sets demonstrate a declining pattern in the density values. Set 2 shows a steeper reduction in density while also achieving a stronger correlation compared to set 1.

ISSN : 2597-4785 (ONLINE)
ISSN : 2597-4750 (PRINTED)



(a)



(b)

Figure 8. Density of mixes against mix variants (a) Set 1, (b) Set 2

B. Compressive strength

Figure 9 illustrates the cube compressive strength of the mixes. All mixes show increasing strength from day seven to the twenty-eighth day. Mix 5 with 0% CC and 100% FC achieved the highest cube compressive strength at 28 days, with a value of 44.2N/mm2, followed by the control mix, 43.45N/mm2. The weakest mix with a value of 32.76 N/mm2 is mix three, which contains 100% CC and 33% FC. Also, it is essential to note that mixes 9 and 10, which undergoes the air curing method, obtained the three lowest compressive strength after mix three, with values of 37.86 N/mm^2 and 38.66 N/mm^2, respectively. Even though theair curing process helps mix 9 and 10 achieve lower density, at the same time, the process doesnot increase the mix's strength as efficiently as water curing. In the air curing method, the moisture needed during cement hydration only comes from the water retained by the lightweight OPBC aggregates. Therefore, it is understandable how the concrete mix that has better hydration when fully submerged in water is more potent than concrete that relies onlyon water retained inside its aggregates.

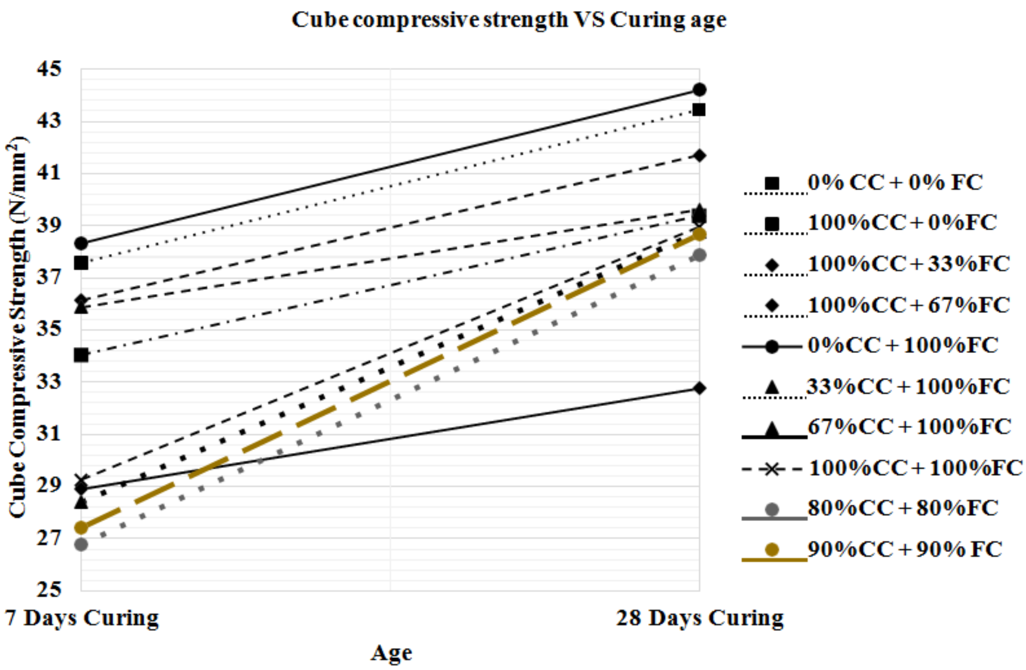
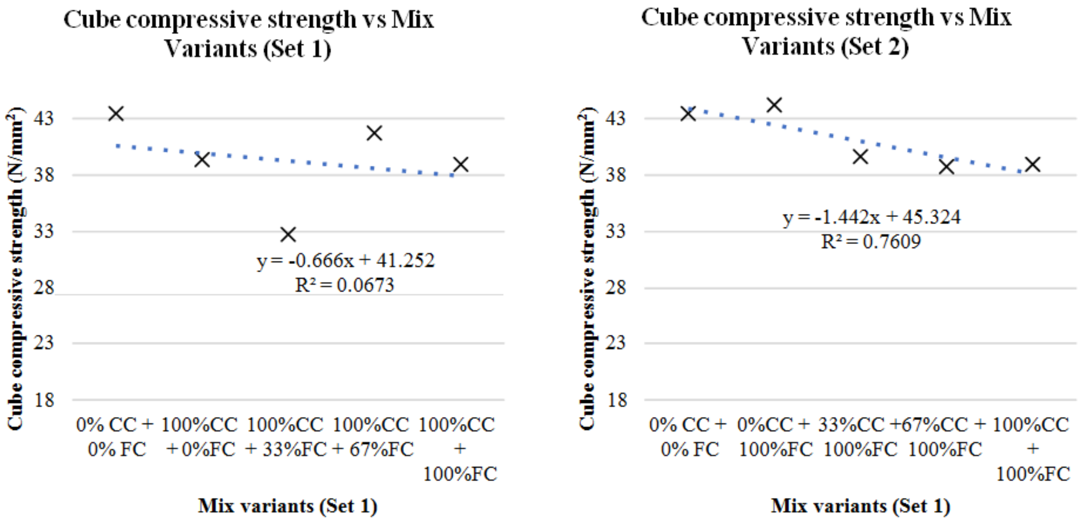


Figure 9. Cube compressive strength of mixes by curing age

:: IJEBD ::
(International Journal of Entrepreneurship and Business Development)
Volume 05 Number 05 September 2022

ISSN : 2597-4785 (ONLINE)
ISSN : 2597-4750 (PRINTED)

Figure 10 (a) and (b) present the cube compressive strength vs mix variants for set 1 and set 2, respectively. Both sets show an overall declining cube compressive strength value when the portion of OPBC in the mix is increased. Similar to the results shown in Figure 8, the second set also shows steeper decrease in strength and higher correlation compared to set 1.



(a) (b)

Figure 10. Cube compressive strength of mixes against mix variants, (a) Set 1, (b) Set 2

Taken into account that this study aims to find an OPBC mix that fulfils the minimum strength for a precast concrete product according to BS EN 13369:2013 and at the same time can be categorized as lightweight concrete conforming to BS EN 206:2013, a graph of the cube compressive strength of all the mixes against their density at 28 days age is plotted, as illustrated in Figure 11. From this plot, it is clear that only mix 9 and 10 satisfy the two conditions.

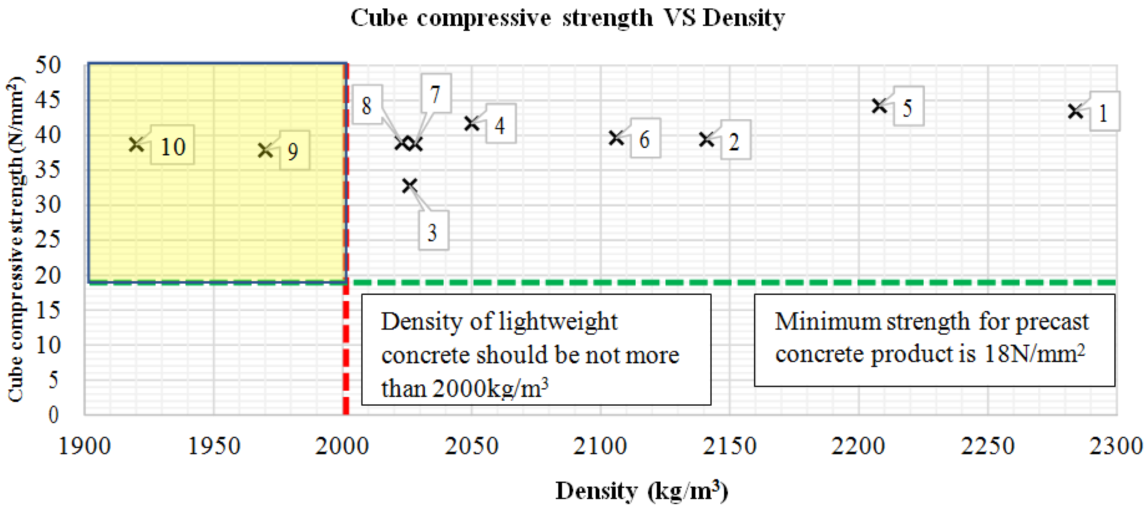


Figure 11. Cube compressive strength against density of concrete mixes

IV. CONCLUSION

The cube compressive strength and density results of various OPBC concrete mix proportions in this study show that the concrete made of OPBC aggregates is as adequate as regular concrete. All OPBC concrete mix in this study passed the minimum strength requirement for precast concrete product. A few conclusions can be drawn from the results.

1. The increase in the amount of OPBC aggregates replacing the portions of natural aggregate in a concrete mix reduces the density of the concrete, as well as the strength ofthe concrete. For future study, the density of the OPBC concrete achieved in this study can be further reduced with the addition of other lightweight fine and coarse aggregate.
2. Air curing produces lighter concrete compared to water curing. This method is useful especially for concrete such as OPBC concrete than contains lightweight aggregate that are able to absorb and retain water. The strength difference between the control concretemix and mix 10 consists of 90% CC and 90% FC cured by air is only 11%. Meanwhile, between mix 10 and mix 8 that contained 100% CC and 100% FC, cured by water, the strength difference is only 0.77%.
3. The best OPBC concrete mix obtained in this study is mix 10 that gained cube compressive strength of 38.66N/mm^2, and density of 1920kg/m^3.

ACKNOWLEDGEMENTS

This research work is supported by the Malaysia Ministry of Education through the HLP scholarship 2017 programme and Universiti Teknologi Malaysia (UTM) through GUP Tier 1 with grant Q.J130000.2522.20H15. We also would like to thank the School of Civil Engineering, Faculty of Engineering, UTM Skudai and Civil Engineering Department of Politeknik Port Dickson for providing facilities and expertise in materialising this study.

REFERENCES

Ahmad, H., Mohd, S., & Noor, N. M. (2007). Mechanical Properties Of Palm Oil Clinker Concrete. *1st Engineering Conference on Energy & Environment (ENCON2007)*. https://www.researchgate.net/publication/259936617_Mechanical_Properties_Of_Palm_Oil_Clinker_Concrete

Aslam, M., PayamShafigh, & Jumaat, M. Z. (2016). Oil-palm by-products as lightweight aggregate in concrete mixture: a review. *Journal of Cleaner Production*, *126*, 56–73. https://doi.org/10.1016/j.jclepro.2016.03.100

Aslam, M., Shafigh, P., Nomeli, M. A., & Jumaat, M. Z. (2017). Manufacturing of high-strength lightweight aggregate concrete using blended coarse lightweight aggregates. *Journal of Building Engineering*, *13*, 53–62. https://doi.org/10.1016/j.jobe.2017.07.002

ASTM C330. (2017). *Standard Specification for Lightweight Aggregates for Structural Concrete*. https://doi.org/10.1520/C0330_C0330M-14

Babu, D. J. S., & Rex, J. (2019). Experimental investigation on lightweight concrete slabs. *International Journal of Recent Technology and Engineering*, *7*(5), 502–506. https://www.researchgate.net/publication/332264410_Experimental_investigation_on_lightweight_concrete_slabs

British Standards Institution. (2009a). *BS EN 12390-3:2009 Testing Hardened Concrete - Part 3: Compressive Strength Of Test Specimens*. https://binamarga.pu.go.id/bintekjatan/otomasi9/index.php?p=show_detail&id=20862&keywords=

British Standards Institution. (2009b). *EN 12350-2:2009 Testing fresh concrete - Part 2: Slump-test*. https://standards.iteh.ai/catalog/standards/cen/370dfa4c-9232-4021-8644-5b748498ed22/en-12350-2-2009

British Standards Institution. (2013a). *BS 1881-125:2013 Testing concrete Methods for mixing and sampling fresh concrete in the laboratory*. https://www.en-standard.eu/bs-1881-125-2013-testing-concrete-methods-for-mixing-and-sampling-fresh-concrete-in-the-laboratory/

British Standards Institution. (2013b). *BS EN 206:2013 Concrete - specification, performance, production and conformity*. https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocID=315767

British Standards Institution. (2018). *BS EN 13369:2018 Common rules for precast concrete products*. https://www.techstreet.com/standards/bs-en-13369-2018?product_id=2014923

Ismail, S., Hoe, K. W., & Ramli, M. (2013). Sustainable Aggregates: The Potential and Challenge for Natural Resources Conservation. *Procedia - Social and Behavioral Sciences*, *101*, 100–109. https://doi.org/10.1016/j.sbspro.2013.07.183

Mo, K. H., Alengaram, U. J., Jumaat, M. Z., & Yap, S. P. (2015). Feasibility study of high volume slag as cement replacement for sustainable structural lightweight oil palm shell concrete. *Journal of Cleaner Production*, *91*, 297–304. https://doi.org/10.1016/j.jclepro.2014.12.021

ISSN : 2597-4785 (ONLINE)
ISSN : 2597-4750 (PRINTED)

Mortazavi, M., & Majlessi, M. (2012). Evaluation of Silica Fume Effect on Compressive Strength of Structural Lightweight Concrete Containing LECA as Lightweight Aggregate. *Advanced Materials Research*, *626*, 344–349. https://doi.org/10.4028/www.scientific.net/AMR.626.344

Nawy, E. G. (1997). *Concrete Construction Engineering Handbook*.

Ng, C. H., Zakaria, I., Sambu, N., Manan, M. A., & Kurian, V. J. (2007). *Engineering Properties of Oil Palm Shell (OPS) Hybrid for Lightweight Precast Floor Slab*. https://www.researchgate.net/publication/279484394_Engineering_Properties_of_Oil_Palm_Shell_OPS_Hybrid_Concrete_for_Lightweight_Precast_Floor_Slab

Sajedi, F., & Shafigh, P. (2012). High-Strength Lightweight Concrete Using Leca, Silica Fume, and Limestone. *Arabian Journal for Science and Engineering*, *37*, 1885–1893. https://link.springer.com/article/10.1007/s13369-012-0285-3

Shafigh, P., Mahmud, H. Bin, Jumaat, M. Z. Bin, Ahmmad, R., & Bahri, S. (2014). Structural lightweight aggregate concrete using two types of waste from the palm oil industry as aggregate. *Journal of Cleaner Production*, *80*, 187–196. https://doi.org/10.1016/j.jclepro.2014.05.051

Shetty, M. S. (2008). Concrete Technology. In *Theory and Practice* (p. 624). S. Chand. https://books.google.co.id/books/about/Concrete_Technology.html?id=YZ8_nwEACAAJ&redir_esc=y

Shi, C., Wu, Z., Lv, K. X., & Wu, L. (2015). A review on mixture design methods for self-compacting concrete. *Construction and Building Materials*, *84*, 387–398. https://doi.org/10.1016/j.conbuildmat.2015.03.079

Teychenné, D. C., Franklin, R. E., Erntroy, H. C., Hobbs, D. W., & Marsh, B. K. (1997). *Design of Normal Concrete Mixes* (2nd ed.). BRE. https://www.brebookshop.com/samples/327970.pdf

V.I, O., I, I. H., C, N. F., & U, O. F. (2014). Sustainable Oil Palm Waste Management in Engineering Development. *Civil and Environmental Research*, *6*(5). https://iiste.org/Journals/index.php/CER/article/view/12826

Yardim, Y., Waleed, A. M. T., Jaafar, M. S., & Laseima, S. (2013). AAC-concrete light weight precast composite floor slab. *Construction and Building Materials*, *40*, 405–410. https://doi.org/10.1016/j.conbuildmat.2012.10.011