CONSTRUCTION
E-ISSN: 2785-8731
VOLUME 4, ISSUE 1, 2024, 28 – 36
DOI: https://doi.org/10.15282/construction.v4i1.10176

RESEARCH ARTICLE

Recycling of Oil Palm Shell as Aggregate in Concrete: A Review

N. Ahmad[1], K. Muthusamy[1]*, R. Embong[1], L. Krishnaraj[2]

[1]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26300 Kuantan, Pahang, Malaysia
[2]Department of Civil Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, Kattankuluthur, 603203, Chengalpattu (Dt), Tamil Nadu, India

ABSTRACT - The consideration of using alternative materials as coarse aggregates in construction industry is to conserve the natural resources, reduce undesirable carbon dioxide (CO2) and environmental degradation related to conventional aggregate. Oil palm shell (OPS) which is a by-product from oil palm industry has shown potentials as an alternative to the conventional aggregate in concrete production. This paper reviews the previous studies on the application of OPS as a construction material and has been extensively used in tropical countries. The performance of OPS meets the minimum requirements for lightweight aggregates. It is suitable material for the production of structural lightweight aggregate concrete with 28-day compressive strength more than 25 MPa. The various improvement techniques employed OPS concrete that resulted in improved OPS concrete performance are also highlighted in this review.

ARTICLE HISTORY
Received : 04 Jan. 2024
Revised : 24 Jan. 2024
Accepted : 22 Feb. 2024
Published : 13 Mar. 2024

KEYWORDS
Oil palm shell;
Environmental pollution;
Lightweight aggregate;
Concrete;
Mechanical properties;

1.0 INTRODUCTION

Concrete which produced by blending cement, sand, water and coarse aggregate is widely used in various types of construction project all over the world. Coarse aggregate is the most important component, playing a significant role in imparting both volume and strength to concrete. It comes from natural resources through rock quarrying or dredging from the river bed. Aggregates are considered the most-abundantly-used materials, besides soil and water since it constitutes up to 75% of the total volume of concrete [1-2]. Aggregates are used in construction for making concrete, asphalt, ballast, and fill materials, in road bases, decorations, filters, drainage, and in various manufacturing processes like metal casting and fluxing, among others. Consequently, the utilization of aggregates is linked to a country's infrastructure development [3]. The basic of coarse aggregate characteristics such as density, particle size, grading and shape have a considerable impact on the stability of fresh concrete [4]. Good strength, durability and impermeability are provided by concrete, making it the ideal substance for building [5]. Overusing traditional aggregates for construction causes problems like reduced natural resources, soil erosion, noise pollution, loss of ecosystems, poor water quality, and lowered water tables [6]. Continuous quarrying activity would result in depletion of natural stone supply that would finally affects the supply chain for concrete production resulting in cost increment of construction cost.

In view of environmental sustainability, other alternative materials need to be discovered to reduce the dependency on natural coarse aggregate supply. There are various synthetic or manufactured materials like foamed slag, expanded clay, shales, perlite, slate, polystyrene, and sintered fly ash, along with artificial cinders, coke breeze, bloated clay, vermiculite, and thermo Cole beads [7]. These alternatives are suitable, especially for Lightweight Aggregate Concrete (LWAC) [8]. Several types of natural and synthetic Lightweight Aggregate (LWA) find application in manufacturing lightweight aggregate concrete. With the depletion of natural LWA sources and the elevated expense of producing synthetic LWA, the demand arises for cost-effective and environmentally friendly alternatives. Utilizing appropriate waste materials as LWA can be the best option [6]. Every year, construction industries use huge quantities of natural aggregates, which leads to depletion of raw materials and degradation of the ecosystem [9]. For future generations, alternative sustainable coarse aggregate has become an urgent need. Due to the depletion of sources of natural LWA and the high manufacturing cost of artificial LWA, there is a need for eco-friendly, coeffective LWA. Using suitable locally available waste material as LWA can be the best option. This paper reviews the previous studies on the application of Oil Palm Shell (OPS) as a construction material. Oil palm shell is one of the farming left over materials that has been extensively used in tropical countries. It has acceptable performance and can satisfy the requirements for lightweight aggregate [6].

2.0 METHODOLOGY

For bibliometric analysis, two databases are mainly recognized: Web of Science (WoS) and Scopus. The Scopus database was used for this study because to its ability to offer a wider range of summaries and citations of literature searches, mostly centered around scientific and technical fields. This database makes it possible to develop connections between fields and measure the impact of study, among other research findings. Proper software is needed to do a proper

*CORRESPONDING AUTHOR | K. Muthusamy | ✉ khairunisa@umpsa.edu.my

bibliometric analysis. "CiteSpace," "CitNetExplorer," "VOSviewer," and "Bibliometrix" are just a few of the many tools and software packages that may be used to undertake a bibliometric analysis, including visualization and quantitative analysis, single analysis, or both at the same time. The "VOSviewer" was chosen due to its ease of use and accessibility. There are five identified clusters, all of which are related to one another. Five clusters are pointed out, being all of them inter-related except one that it has no relation with the other keywords. The first cluster (#1) incorporates words such as “ops”, “palm shell”, and “compressive strength”. The second cluster (#2) corresponds to topics more related to “structural performance” and “characteristic” in building. The third cluster (#3) takes into account is the “size”, “curing age” and “negative impact”. Observing the isolated cluster (#4), it has three related keywords “agriculture waste”, “construction material” and “application”. The last cluster (#5) is related to “lightweight concrete” and “volume fraction”.

2.1 The Network Visualization of Literacy Topic Area

Figure 1 shows that there is a lot of research being done on the development and use of new types of lightweight concrete, such as oil palm shell concrete and structural lightweight aggregate concrete. These types of concrete have the potential to be more sustainable than traditional concrete, and they can be used in a variety of structural applications.

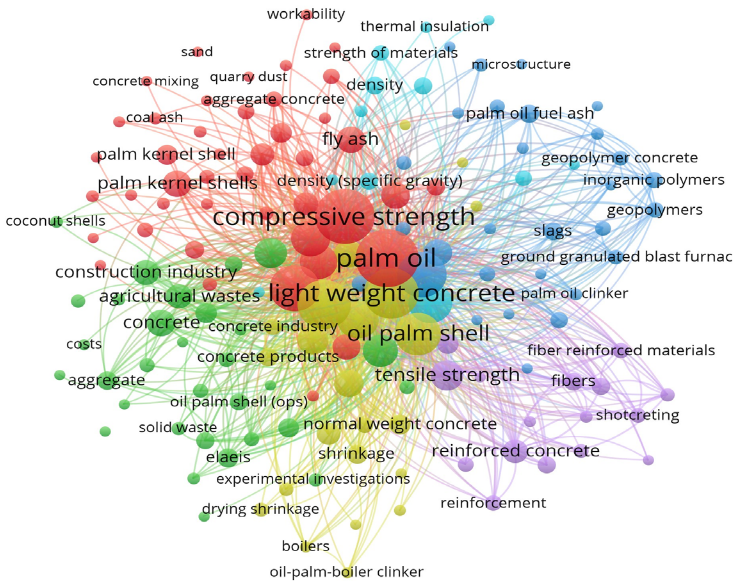

Figure 1. Co-occurrence between the keywords

2.2 The Network Visualization of Literacy Authors

A network of co-authors is presented in Figure 2, making use of node and edge representations. The size and thickness of a node are proportional to the author's influence in the field, visually portraying the weight of their contributions. The bigger and thicker the node, the more impactful and respected the author is, leading to a deeper understanding of their standing in the field.

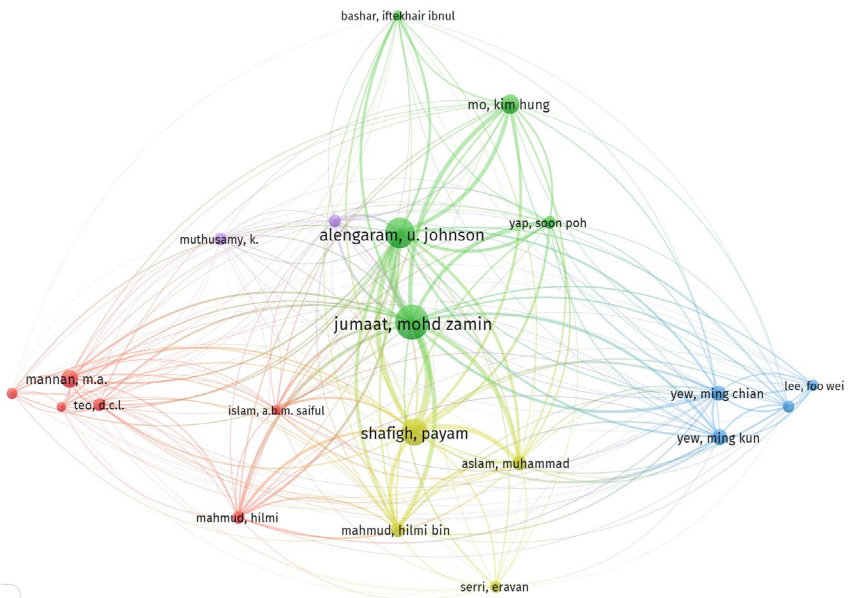

Figure 2. Network visualization for authors

2.3 The Density Visualization for Country Co-Authorship

Figure 3 shows the position of Malaysia in the network is a strong research base, while the connections to Indonesia and the United States highlight cross-regional knowledge exchange. This geographically diverse co-authorship pattern research positions within a global context, potentially enriching its impact and reach.

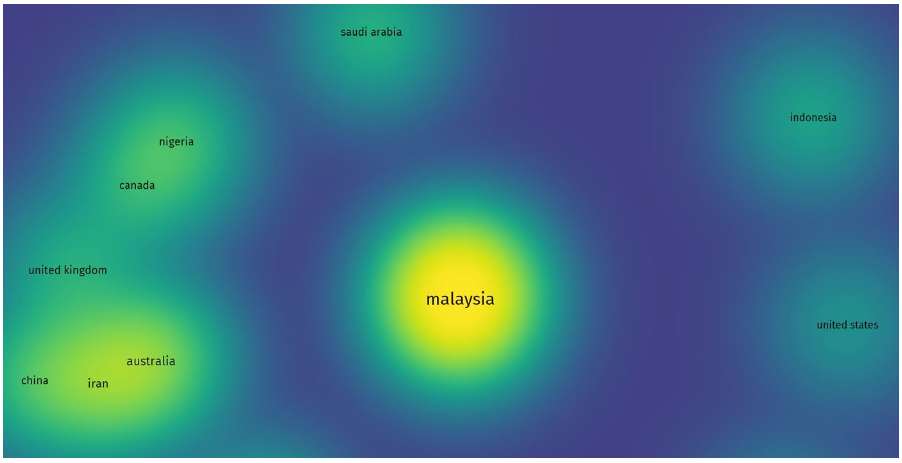

Figure 3. Density visualization map for country co-authorship

3.0 OIL PALM SHELL GENERATION AND ENVIRONMENTAL IMPACT

Malaysia being the largest oil palm producer in the world, has a total planted area coverage of 3.8 million hectares[10]. The cross-section of oil palm fruit consists of the outer skin, the exocarp, follow by three inner layers (Figure. 4). The first inner layer or mesocarp provides the palm oil while the layer next to mesocarp is the hard shell, the endocarp known as OPS which housed the inner layer identified as palm kernel, the source of palm kernel oil and palm kernel cake used as livestock feed. OPS constitute an estimate of 5.5% of the palm fruit bunches from oil palm trees [11][12] and 10–11% of palm fruit from palm fruit bunches. The waste is generated from oil palm milling process and with more than 270 palm oil mills operating in the country, nearly more than 2.4 million tones of palm shell wastes are produced annually [13]. The processing of palm fruit for palm oil and palm kernel extraction creates many wastes (empty bunches of fruit, palm oil fibre, palm oil efluent, OPS) which, when not properly disposed of to the environment, are toxic to living organisms [14]. OPS is a solid waste material which is obtained as a by-product from the processing of oil palm fruit [14]. The estimated quantity of waste biomass materials is approximately 90 million tons, which regarded as palm oil mill waste and hazardous elements [15]. These wastes are available in two forms as solid and effluent. A large sum of the waste is left strewn in landfills that accumulate over the years which is hazardous to the environment and nearby communities[16] Each year, the palm oil industry generates a significant amount of biomass residue and effluent waste; both have been identified as significant sources of greenhouse gas (GHG) emissions [17]. The escalation of (GHG) emissions plays a pivotal role in shaping the impact of global climate change, thereby necessitating urgent and concerted measures aimed at mitigating the consequences of this change and enhance the future environment [18]. To produce one tonne of crude palm oil, about 6 tons of water is used out of which 50% is converted to wastewater or palm oil mill effluent (POME)[19]. The POME, rich in BOD, COD, and oil and grease, with few hazardous materials such as siloxanes, fatty acid methyl ester, and phenolic compounds that may significantly increase the risk of violating the effluent quality standards [20]. Insufficient handling of waste management poses a dire threat, with the potential to significantly adverse impact both the environment and the population (Figure 5).

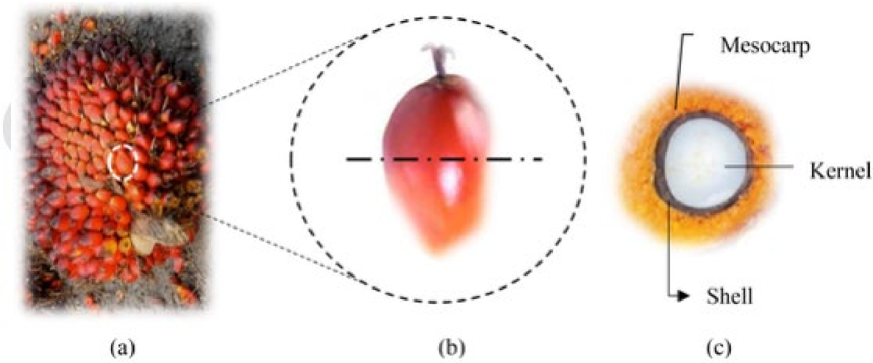

Figure 4. Image of (a) oil palm fruit bunch, (b) palm fruit (c) cross section of palm fruit [21]

Figure 5. OPS deposit at oil palm processing industries [11]

4.0 PHYSICAL PROPERTIES

OPS has various shapes depending on palm oil processing method adopted at the mill. The color of OPS varies from dark gray to black. The color of oil palm shell (OPS) is generally not a direct indicator of its strength. The strength of OPS is influenced by various factors, and color alone is not a reliable measure [22]. The shape of OPS varies from angular to polygonal depending on nut breaking methods. The shape, surface texture, size, and thickness of OPS are important factors in determining the behavior of aggregates in both plastic and hardened states, affecting workability, water requirements, cement content, as well as strength and durability [23]. The physical properties of OPS (Table 1) determines the behavior of LWA obtained from the palm oil industry.

Table 1. Physical properties of OPS

Ref.	Maximum size (mm)	Specific gravity	Bulk density (kg/m^3)	Fineness modulus (FM)	Aggregate impact value (%)	Water absorption for 24 h (%)	Aggregate abrasion value (%)	Flakiness index (%)
[26]		1.17	590	6.24	7.86	23.30	4.80	65.17
[27]		1.23	685	5.92		18.69		
[28]	12.5	1.22	683	5.72		18.73		
[29]	12.5	1.17	590	6.24	7.86	23.30		65.17
[30]		1.27	620	6.24	3.91	24.50		
[11]	12.5	1.17	600	6.08	7.51	33.00	4.90	
[31]	9.5	1.17	592	6.24		23.32	4.80	
[32]	9.5	1.33	628		2.35	23.50		
[33]		1.19	610		5.50	20.50	5.70	
[25]	9.0	1.35	658	4.71	2.63	19.10		
[23]	12.7	1.14	545				3.05	
[34]	16.0	1.31	530			19.93	5.02	
[35]	12.5	1.17	590	6.24	7.86	23.30	4.80	65.17
[36]	9.0	1.35	658		2.63	19.10		
[37]	12.5	1.17	592	6.24	7.86	23.32	4.80	

OPS with shell thickness ranging from approximately 0.15 to 8.0 mm. The thickness of OPS varies based on species and age categories [6], [22]. OPS shape differs between flaky irregular, angular and polygonal with high flakiness index of about 65 % [23]. Figure 6 shows the diverse sizes of uncrushed and crushed OPS. OPS is lighter than the conventional coarse aggregate which appear solid like. The specific gravity of oil palm shell (OPS) is linked to its density, affecting the strength of OPS concrete. The compressive strength of OPS lightweight concrete ranges from 17-35 MPa, with fully treated OPS yielding the highest strength. This suggests that the specific gravity of OPS can indirectly affect its strength [26]. Consequently, the resulting concrete are lightweight compared to plain concrete.

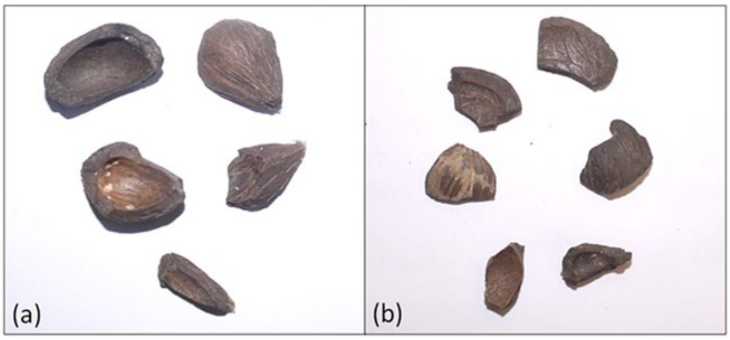

Figure 6. (a) Uncrushed and (b) crushed OPS [25]

5.0 CHEMICAL PROPERTIES

The chemical analysis of OPS demonstrated its composition of various oxides, chemical compounds, and elements, as detailed in Table 2. The observed variations in OPS properties can be attributed to multiple factors, including species or varieties, climate, geographical location, OPS origin, treatment, and processing methods [6]. Being an organic material, this material has sour smell. Generally, OPS predominantly comprise SiO_2, followed by Al_2O_3, CaO, and MgO as its major components. However, the chemical properties of OPS are notably altered after surface treatment. Treated OPS exhibits higher levels of CaO and MgO but lower levels of SiO_2, Al_2O_3, SO_3, and loss on ignition compared to untreated OPS.

Table 2. Chemical properties of OPS

	Oxide composition (%)							
Ref.	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	SO3
(Ahmmad et al., 2016)	46.61	3.33	10.19	14.76	2.91	1.15	9.88	7.84
(M.K Yew et al., 2015)	21.28	5.6	3.36	64.64	2.06			
(M. Krishnamurthy, 2019)	51.4	27.5	7.2	4.3	2.8			0.2

Note: ∗ Values varied for treated and untreated OPS

6.0 MIX DESIGN OF OPS CONCRETE

The mixing ingredients used for oil palm shell concrete (OPSC) is cement, fine aggregate, oil palm shell (OPS) as coarse aggregate replacement, water and superplasticizer. When making concrete, OPS can be used in place of traditional stone aggregates (100% OPS).The cement needed is between 450 kg/m^3 to 550 kg/m^3 to determine the suitable mix design of environmentally friendly concrete, and ultimately recommended the use of locally available materials, such as OPS [26] The past researches observed incorporation of OPS into normal weight aggregate (NWA) generally results in lower workability and mechanical strength concrete which further decrease with increasing addition of 100% OPS in concrete. Furthermore, the higher water absorption rate of oil palm shell concrete (OPSC) compared with normal weight concrete (NWC). However, the use of superplasticizer and heat treatment of OPS prior application in OPSC mix can be used to improve the workability of OPSC [3]. Different mix proportioning methods were employed in the preparation of concrete mix containing OPS to produce concrete with the targeted strength. There are mix proportions for lightweight OPSC have been demonstrated by various researchers [30-31].Abdul Rahman et al. [32]incorporated 25 kg/m^3 steel fibre in 432 kg/m^3 concrete (about 6%) in additional material to improve the strength of OPS concrete. Another researcher Serri et al., [30] utilized OPS which have been left outside the laboratory for 6 months to expose them to natural environment because there might be fibre and oil coating on the surface of fresh OPS before integrating in concrete mixture.

7.0 DENSITY AND COMPRESSIVE STRENGTH

Fresh properties such as the workability of concrete are primarily affected by the inclusion of different coarse aggregates. The physical properties of aggregate, such as particle size, specific gravity, bulk density, water absorption, etc., strongly influence concrete slump value [31]. Workability which is the parameter used for the evaluation of fresh concrete properties is determined through slump test [6][32]. Understanding of fresh properties of concrete is important due to its usefulness in controlling the rheology, rate of setting, hardening and durability of concrete [33] The slump ranging between 50 and 75 mm which is considered good workability for LWAC by [34]. The slump value of fresh concrete mostly depends on the mix proportions, material type, and environmental constrains [35]**.** The density of LWAC is a principal property used in determining the quality of concrete[16]. The fresh concrete density gives the indication whether hardened concrete is ultra-lightweight, lightweight or structural lightweight or normal weight or heavy weight [35]. Studies have shown the reduction in concrete density as the substitution ratio of OPS increases. Compressive strength is a significant property of concrete because it directly impacts on other properties like splitting tensile strength, flexural strength and modulus of elasticity of concrete [14]. The findings from previous studies the compressive strength of concrete accommodating OPS as coarse aggregate is usually less than NWC due to less density and bending force. The strength of concrete is directly proportional to the aggregate strength, stiffness and density and inversely proportional to the porosity of aggregates [38-39]. Addition of OPS generally caused a decrease in compressive strength of concrete [37]. Lightweight concrete using OPS as coarse aggregate is able to produce concretes with compressive strengths of more than 25 MPa[11].Structural OPSC of different strength grades with OPS as full replacement for natural aggregate can be produced [3]

8.0 FLEXURAL STRENGTH

The 28-day flexural strength of the OPS concrete ranged from 4.42 to 6.99 MPa [37]. Previous studies [22] and [36] revealed that OPS concretes have flexural strength in the range of 2.13–4.93 MPa. It was reported [34] that the flexural strength of NWC with a compressive strength of 34–55 MPa is in the range of 5–6 MPa and a flexural/compressive strength ratio is in the range of 11.6–13.5%. The low dosage of different type of polypropylene (PP) fibres and aspect ratio in concrete has positive effect on the splitting tensile and flexural strengths. The effects of incorporating of PP fibres and aspect ratio at low volume fractions up to 0.5% improve the mechanical properties of high-strength oil palm shell lightweight concrete. The incorporation of unit percentage of steel fiber increases the rate of flexural strength up to 17% [41]. For example, the flexural strength test result of the OPS lightweight concrete is illustrated in Figure 7. The flexural strength of the concrete specimens for all the mixes increased with increase in curing days. The 12 mm OPS concrete specimens obtained the highest strength (2.85 MPa) [42].

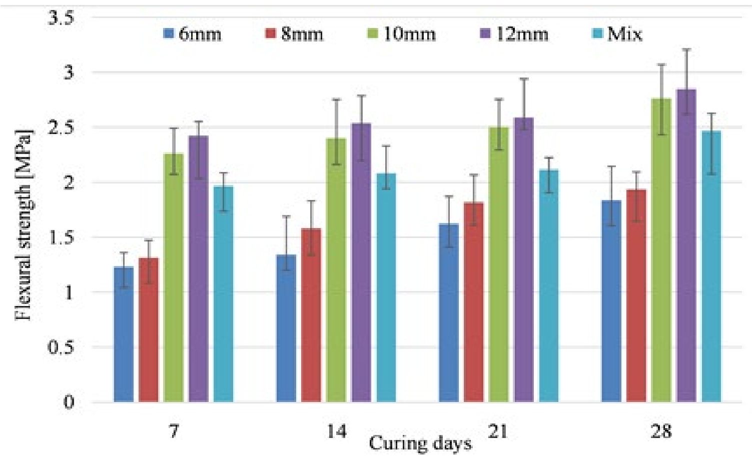

Figure 7. Flexural strength of concrete specimens with different sizes of OPS [38]

9.0 SPLITTING TENSILE STRENGTH

Splitting tensile strength is a key framework used to evaluate concrete strength against cracking [39] The 28-day splitting tensile strength of crushed OPS concretes was 6.7–8.1% of the compressive strength. Generally, the splitting tensile strength of concrete is 8–14% of the compressive strength [40]. [37] observed that the splitting tensile strength increases with increasing compressive strength. The measured 28-day splitting tensile strength is in the range of 2.85–3.54 MPa. Factors such as aggregate size, curing age and replacement level of crushed granite are responsible for decrease in splitting tensile strength of concrete [41] The splitting tensile strength of OPSC decreased as observed for its compressive strength as the replacement level of OPS and this is responsible for early crack development when loaded [42] [43] observed that the addition of different types of PP fibres greatly increased the splitting tensile strength of concrete. For example, Figure. 8 presents correlations between tensile strength and volume fraction of steel fibers in POC based high-strength lightweight concrete (HSLWC) at 28 days [44].

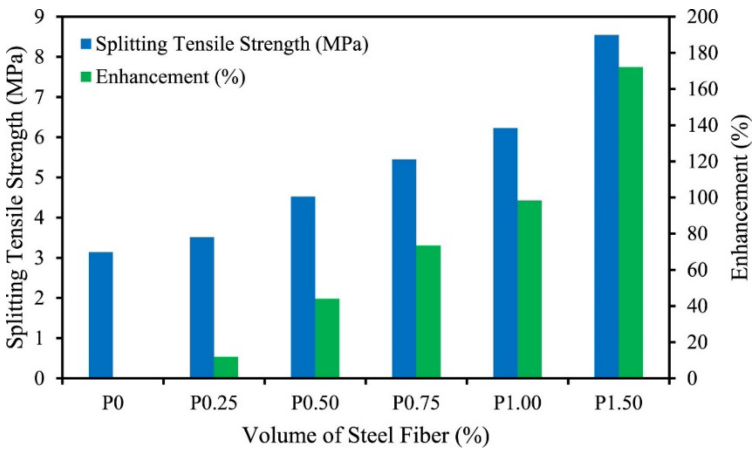

Figure 8. Splitting tensile strength versus volume of steel fibers [44]

10.0 MODULUS OF ELASTICITY

Modulus of elasticity (MOE) is an important material property used to measure the material resistance to the axial deformation [45]. The lower MOE value of concrete, the higher is the tendency to produce greater deflection, the modulus of elasticity of the OPSC and OPBCC mixes were 7.9 and 15.7, respectively. The OPS concrete was considered as a concrete with low elastic modulus, while the replacement of OPS by 50% oil-palm-boiler clinker (OPBC) aggregates significantly increased the modulus of elasticity by about 50% [46]. The Modulus of elasticity (MOE) value of concrete depends on coarse aggregate stiffness, elastic properties of constituent materials, and interfacial zone connecting the paste and coarse aggregates [36]. Figure. 9 shows that the performance of OPSC upon incorporation of palm oil fuel ash as partial cement replacement material. Research works carried out in the past on POFA-blended concrete also concluded that ground POFA did not have significant effect on the MOE of concrete [47].

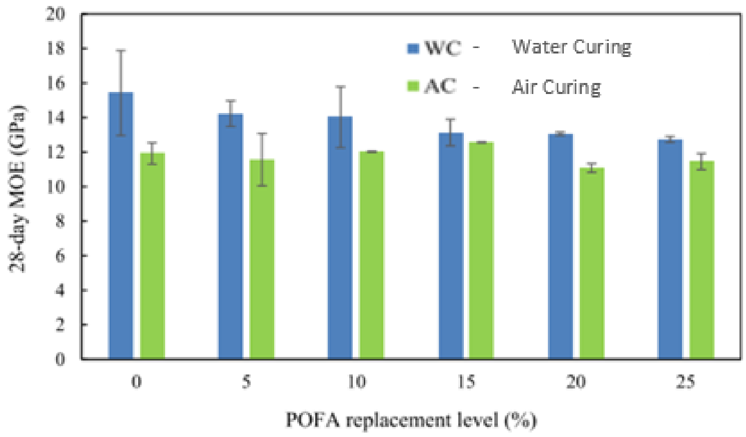

Figure 9. 28-d MOE for all mixes subjected to different curing conditions [47]

11.0 CONCLUSION

This review paper show that the use of OPS as an alternative aggregate in concrete is effective and sustainable, based on the positive results obtained from previous studies. OPS aggregate has irregular shape, including circular, oval, flaky or polygonal. OPS aggregate has specific gravity ranging from 1.14 to 1.35, which is lower than normal aggregate typically is 2.5 to 3.0, and can be termed as lightweight aggregate. The low workability of OPS can be treated by adding a superplasticizer. Generally, the compressive strength of OPSC is more than 25 MPa. OPSC is more economical and environment-friendly than Normal Weight Concrete (NWC) potentially resulting in lower cost of production.

12.0 ACKNOWLEDGEMENT

The authors would like to thank the Faculty of Civil Engineering Technology for research facilities provided.

13.0 AUTHOR CONTRIBUTIONS

Norasyimah Ahmad: Writing- Original draft preparation
Khairunisa Muthusamy: Reviewing and Editing
Rahimah Embong: Reviewing and Editing
Loganathan Krishnaraj: Reviewing and Editing

14.0 FUNDING

The support provided by Universiti Malaysia Pahang Al-Sultan Abdullah in the form of a research grant vote number RDU1803160 for this study is highly appreciated.

15.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

16.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

17.0 REFERENCE

[1] A. Neville, Properties of concrete CTP-VVP, Malaysia, 2008.

[2] C. Deepa, K. SathiyaKumari and V. P. Sudha, "Prediction of the compressive strength of high-performance concrete mix using tree based modeling," *International Journal of Computer Applications*, vol. 6, pp. 18–24, 2010.

[3] M. A. Kareem, A. A. Raheem, K. O. Oriola, and R. Abdulwahab, "A review on application of oil palm shell as aggregate in concrete - Towards realising a pollution-free environment and sustainable concrete," *Environmental Challenges*, vol. 8, p. 100531, 2022.

[4] B. Esmaeilkhanian, K. H. Khayat, A. Yahia, and D. Feys, "Effects of mix design parameters and rheological properties on dynamic stability of self-consolidating concrete," *Cement and Concrete Composites*, vol. 54, pp. 21–28, 2014.

[5] B. D. Tongbram, H. K. Singh, and V. V. Devi, "A comparative study on partial replacement of coarse aggregates in concrete with sustainable waste materials," *Materials Today*, [In press], 2023.

[6] H. M. Hamada, B. S. Thomas, B. Tayeh, F. M. Yahaya, K. Muthusamy, and J. Yang, "Use of oil palm shell as an aggregate in cement concrete: A review," *Construction and Building Materials*, vol. 265, p. 120357, 2020.

[7] M. Balat, "Mechanisms of thermochemical biomass conversion processes," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 30, pp. 620–635, 2008.

[8] B. Vakhshouri and S. Nejadi, "Review on the mixture design and mechanical properties of the lightweight concrete containing expanded polystyrene beads," *Australian Journal of Structural Engineering*, vol. 19, no. 6, pp. 1–23, 2017.

[9] W. Aziz. M. Aslam, M. F. Ejaz et al., "Mechanical properties, drying shrinkage and structural performance of coconut shell lightweight concrete," *Structures*, vol. 35, pp. 26–35, 2022.

[10] D. C. L. Teo, M. A. Mannan, V. J. Kurian, and C. Ganapathy, "Lightweight concrete made from oil palm shell (OPS): Structural bond and durability properties," *Building and Environment*, vol. 42, no. 7, pp. 2614–2621, 2007.

[11] D. C. L. Teo, M. A. Mannan, and V. J. Kurian, "Structural performance of lightweight concrete," *Conference on sustainable building Southeast Asia*, vol. 3, pp. 254–258, 2005.

[12] G. Afeti, "Value chain analysis of the oil palm sector in Liberia: An assessment of the skills needs and training providers," Inception Report, Association for the Development of Education in Africa, pp. 1-26, 2016.

[13] M. D. Kawser and F. D. Ani, "Oil palm shell as a source of phenol," *Journal of Oil Palm Research*, vol. 12, no. I, p. 86-94, 2000.

[14] M. A. Kareem, B. O. Orogbade, E. O. Ibiwoye, and N. O. Olasupo, "The use of palm oil mill effluent as mixing and curing water in cement-based composite," *Silicon*, vol. 14, no. 3, pp. 1285–1296, 2022.

[15] M. I. Shahidul, M. L. Malcolm, S. Begum, M. S. J. Hashmi, M. S. Islam, and J. J. Eugene, "Renewable energy production from environmental hazardous palm oil mill waste materials: A review," *Encyclopedia of Renewable and Sustainable Materials*, vol. 2, pp. 902-914, 2020.

[16] H. M. Hamada, B. S. Thomas, B. Tayeh, F. M. Yahaya, K. Muthusamy, and J. Y. Hussein, "Use of oil palm shell as an aggregate in cement concrete: A review," *Construction and Building Materials*, vol. 265, no. 1230357, 2020.

[17] P. Kahar, N. Rachmadona, R. Pangestu et al., "An integrated biorefinery strategy for the utilization of palm-oil wastes," *Bioresource Technology*, vol. 344, p. 126266, 2022.

[18] J.C. Labraga and M. Lopez, "A comparison of the climate response to increased carbon dioxide simulated by general circulation models with mixed-layer and dynamic ocean representations in the region of South America," International Journal of Climatology, vol. 17, no. 15, pp. 1635–1650, 1997.

[19] A.F.M Udaiyappan, H. A. Hasan, M. S. Takriff et al., "Microalgae-bacteria interaction in palm oil mill effluent treatment," *Water Process Engineering*, vol. 35, p. 101203, 2020.

[20] R. A. A. Meena, J. Merrylin, J. R. Banu et al., "A review on the pollution assessment of hazardous materials and the resultant biorefinery products in Palm oil mill effluent," *Environmental Pollution*, vol. 328, 2023.

[21] I. Uchegbulam, E. O. Momoh, and S. A. Agan, "Potentials of palm kernel shell derivatives: A critical review on waste recovery for environmental sustainability," *Cleaner Materials*, vol. 6, p. 100154, 2022.

[22] D. C. Okpala, "Palm Kernel Shell as a Lightweight Aggregate in Concrete," vol. 25, no. 4, pp. 291-296, 1990.

[23] A. A. Azahar, M. D. Nurhafizah, M. R. Omar, N. Abdullah, and A. Ul-Hamid, "Bio-graphene production from oil palm shell waste valorised through sequential thermal and catalytic means," *Carbon Trends*, vol. 9, pp. 100225, 2022.

[24] M. K. Yew, "Mechanical properties and durability of fibre reinforced oil palm shell high strength lightweight concrete," Thesis, Universiti Malaya, Malaysia, 2015. [Online]. Available: https://api.semanticscholar.org-/CorpusID:138105562

[25] S. P. Yap, C. H. Bu, U. J. Alengaram, K. H. Mo, and M. Z. Jumaat, "Flexural toughness characteristics of steel-polypropylene hybrid fibre-reinforced oil palm shell concrete," *Materials & Design*, vol. 57, pp. 652–659, 2014.

[26] M. Gibigaye, G. F. Godonou, R. Katte, and G. Degan, "Structured mixture proportioning for oil palm kernel shell concrete," *Case Studies in Construction Materials*, vol. 6, pp. 219–224, 2017.

[27] C. G. M.A Mannan, "Mix design for oil palm shell concrete," *Cement and Concrete Research*, vol. 31, no. 9, pp. 1323–1325, 2001.

[28] K. Muthusamy, A. M. A. Budiea, N. W. Azhar et al., "Durability properties of oil palm shell lightweight aggregate concrete containing fly ash as partial cement replacement," *Materials Today: Proceedings*, vol. 41, pp. 56–60, 2021.

[29] N. A. Rahman, A. S. H. Tan, F. Waqbitu, and N. H. Roslan, "The effectiveness of oil palm shell (OPS) as major aggregate replacement in concrete," *IOP Conference Series: Earth and Environmental Science*, vol. 476, p. 012019, 2020.

[30] E. Serri, M. Azree, O. Mydin, and Z. Suleiman, "Thermal properties of oil palm shell lightweight concrete with different mix designs," *Jurnal Teknologi*, vol. 70, no. 1, pp. 155-159, 2014.

[31] M. M. Nihar Ranjan Mohanta, "Alternative coarse aggregate for sustainable and eco-friendly concrete - A review," *Journal of Building Engineering*, vol. 59, no. 1, p. 105079 2022.

[32] K. H. Mo, S. P. Yap, U. J. Alengaram, M. Z. Jumaat, and C. H. Bu, "Impact resistance of hybrid fibre-reinforced oil palm shell concrete," *Construction and Building Materials*, vol. 50, pp. 499–507, 2014.

[33] S. (Ed.). Mindess, *Developments in the Formulation and Reinforcement of Concrete.* Woodhead Publishing, 2019.

[34] P. K., & M. P. J. Mehta, "Concrete: microstructure, properties, and materials," 2014.

[35] C. G. M.A Mannan, "Concrete from an agricultural waste-oil palm shell (OPS)," *Building and Environment*, vol. 39, no. 4, p. 441-448, 2004.

[36] M. A. Mannan and C. Ganapathy, "Engineering properties of concrete with oil palm shell as coarse aggregate," *Construction and Building Materials*, vol. 16, no. 1, pp. 29-34 2002.

[37] P. Shafigh, M. Z. Jumaat, H. Bin Mahmud, and N. A. A. Hamid, "Lightweight concrete made from crushed oil palm shell: Tensile strength and effect of initial curing on compressive strength," *Construction and Building Materials*, vol. 27, no. 1, pp. 252–258, 2012.

[38] H. Danso and F. Appiah-Agyei, "Size variation of palm kernel shells as replacement of coarse aggregate for lightweight concrete production," *Open Journal of Civil Engineering*, vol. 11, no. 1, pp. 153–165, 2021.

[39] K. H. Mo, U. J. Alengaram and M. Z. Jumaat, "Utilization of ground granulated blast furnace slag as partial cement replacement in lightweight oil palm shell concrete," *Materials and Structures*, vol. 48, pp. 2545–2556, 2015.

[40] S. H. Kosmatka, B. Kerkhoff and W. C. Panarese, *Design and control of concrete mixtures,* Portland Cement Association, 2002.

[41] J. N. Farahani, P. Shafigh, B. Alsubari, S. Shahnazar, and H. Mahmud, "Engineering properties of lightweight aggregate concrete containing binary and ternary blended cement," *Journal of Cleaner Production*, vol. 149, pp. 976–988, 2017.

[42] S. Khan, S. P. Yap, C. G. Tan, R. Ganasan, M. M. Sherif, and A. El-Shafie, "Torsional behaviours and crack localization in palm oil clinker concrete," Materials, vol. 14, no. 18, p. 5446, 2021.

[43] M. K. Yew, H. Bin Mahmud, B. C. Ang, and M. C. Yew, "Influence of different types of polypropylene fibre on the mechanical properties of high-strength oil palm shell lightweight concrete," *Construction and Building Materials*, vol. 90, pp. 36–43, 2015.

[44] M. A. Hosen, M. I. Shammas, S. K. Shill et al., "Investigation of structural characteristics of palm oil clinker based high-strength lightweight concrete comprising steel fibers," *Journal of Materials Research and Technology*, vol. 15, pp. 6736–6746, 2021.

[45] M. A. Kareem, A. A. Raheem, K. O. Oriola, and R. Abdulwahab, "A review on application of oil palm shell as aggregate in concrete - Towards realising a pollution-free environment and sustainable concrete," *Environmental Challenges*, vol. 8, p. 100531, 2022.

[46] M. Aslam, M. Z. Jumaat, and P. Shafigh, "High strength lightweight aggregate concrete using blended coarse lightweight aggregate origin from palm oil industry," *Sains Malaysiana*, vol. 46, no. 4, pp. 667–675, 2017.

[47] M. M. U. Islam, K. H. Mo, U. J. Alengaram, and M. Z. Jumaat, "Mechanical and fresh properties of sustainable oil palm shell lightweight concrete incorporating palm oil fuel ash," *Journal of Cleaner Production*, vol. 115, pp. 307–314, 2016.