Scientific Research Journal,
Vol 18, No 2 (2021) 103-117
https://doi.org/10.24191/srj.v18i2.11396

Effect of Utilisation of Nano POFA on Performance of Self-Consolidating High-Performance Concrete (SCHPC)

Nuradila Izzaty Halim[1*], Aidan Newman[1], Muhd Norhasri Muhd Sidek [1,2] Hamidah Mohd Saman[1], Nurul Huda Suliman[1]

[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Malaysia
[2]Institute of Infrastructure Engineering and Sustainable Management (IIESM), UiTM Shah Alam, 40450 Shah Alam, Selangor Malaysia

[*]Corresponding author's e-mail: 2019836164@student.uitm.edu.my

Received: 3 December 2020
Accepted: 28 July 2021
Online First: 31 August 2021

ABSTRACT

Malaysia's palm oil industry plays a significant role in the country's economy. However, a large amount of palm oil fuel ash (POFA), a by-product of this industry, may negatively affect the environment and human health. Hence, this study hypothesized that POFA might be re-used in the form of replacement in concrete to lessen the risk to the environment or human health. Self-consolidating high-performance concrete (SCHPC) has been innovating progressively over the years. In this paper, SCHPC is innovated by utilising nano POFA (NaPOFA) to improve its performance. The POFA performance greatly improved when the particle size is reduced because the finer forms of POFA react effectively with the other constituent materials to produce stronger concrete. Hence this paper presents the experiment of the effect of utilisation of NaPOFA as a replacement to cement ranging between 0% and 10% to produce a self-consolidating high-performance concrete with good workability. The tests conducted were the flow table and compression test. The specimen used in the compression tests were 50 mm concrete cubes, tested in 1, 3, 7, 14, and 28 days. It was found that the inclusion of 1% POFA as a replacement to cement in concrete produced the highest compressive strength, 73.31 MPa, on the 28th day of testing. It was also found that its workability was as good as the control concrete.

Thus, the utilisation of POFA could be considered environmental-friendly since it can be used as cement replacement and enhance the performance in terms of workability and strength.

Keywords: NaPOFA (nano palm oil fuel ash), cement replacement, workability, compressive strength, self-consolidating high-performance concrete

INTRODUCTION

The palm oil industry is one of the major agro-industries in Malaysia. Malaysia has come out as the world's second-largest producer of the product, after Indonesia, with a percentage of 32% in global palm oil production in 2017 [1]. Oil palm planted area in Malaysia in the year 2019 has increased to 5.90 million hectares, with an increment of 0.9% over 5.85 million hectares in 2018 [2]. As palm oil production in Malaysia is increasing continuously, a huge amount of ashes will be produced, leading to environmental pollution, which needs to be considered in managing the waste. POFA is a product obtained from the burning of palm oil fibers, empty fruit bunches, and shells as fuel in palm oil mill boilers [3]. After the burning process, these ashes are disposed of abundantly in a landfill since it doesn't have any commercial value. However, to solve the issue, many researchers have contributed POFA in their studies. They conclude that the use of POFA as a pozzolanic material has improved the mechanical properties and durability of the concrete [4–8].

The main reason POFA is used as cement replacement is due to its good pozzolanic reaction. [9] reported that the use of partial cement replacement of POFA as a pozzolanic material enhanced the mechanical and durability properties of the concrete. Besides, [6] indicates that high contents of silicon dioxide or calcium oxide in POFA produce an additional hydration process, resulting in the enhancement of the concrete strength and durability. Studies by [10] stated that ground POFA could be used alone or with other supplementary cementing materials in producing concrete possessing a better resistance to chloride penetration comparing to OPC concrete. Finer particles of POFA increased the pozzolanic activity, reducing the amount of calcium hydroxide in the concrete mix, improve fresh and mechanical concrete properties, and enhance the durability of concrete [11].

However, a finer size of POFA achieved by grinding has a better effect than micro size POFA. The pozzolanic reaction can be enhanced by grinding [3, 9, 12–15]. Recently, a study on nano-sized POFA has improved the mechanical and durability of mortars and cement paste [6, 16]. According to [6], utilisation of nPOFA (nano-size POFA) particles has shown convincing pozzolanic behaviors and filler actions in producing a dense and closely packed microstructure of the hardened cement pastes. Also, [6, 16] indicated that the effect of nPOFA on early age compressive strength is not remarkable as it absorbed the free water within cement matrices and inhibited cement hydration by adhering to cement particles. However, the compressive strengths increased as the age increased due to the further formation of C-S-H through pozzolanic reactions.

On the other hand, High strength concrete (HSC) is defined as concrete with a compressive strength between 40 to 100 N/mm2. This statement is supported by [17], and he claims that concrete with compressive strength of 80 to 100 N/mm2 and even higher is usually used in precast and in-situ works. High-strength concrete has been widely used in Malaysia since it benefits more applications in the construction industry in terms of strength and durability than regular strength concrete. The low water-cement ratio usually contributes to the development of high-strength concrete. This low water-cement ratio is formed when a high amount of cement is used over water. Also, the use of superplasticizers is mandatory for concrete with a low water-cement ratio to maintain workability. The addition or replacement of cement with supplementary cementing material produces an additional strength of the pozzolanic reaction.

Many studies are done on the utilisation of POFA in producing high-strength concrete, and they concluded that pozzolanic properties of POFA enhance the durability and strength of concrete [8, 12]. POFA has been found suitable to be used as a new supplementary cementing material in making high-strength concrete which gives high compressive strength results up to 50MPa - 80MPa [12, 18–20]. [21] indicated that 10% of POFA replacement gives result in the highest slump value, and the slump values tend to reduce as the POFA replacement value increased further up to 25% due to the more significant effect of the increment of water demand by POFA, resulting in the decrement on the workability of the concrete. Also, [22] in his study has recommended that the use of POFA as cement replacement should not be more than 10% by weight of the binder.

The concrete that was acknowledged as high-strength concrete at the end of year 1970s is now known as high-performance concrete since it shows an enhanced performance on strength, durability, and abrasion resistance [23]. So, HPC can be well-defined as an engineered concrete that enhancing the concrete properties through material selection and proportioning. Self-consolidating cement (SCC) is a non-segregating concrete that is highly flowable and able to spread into the form under its self-weight without requiring mechanical vibration. This concrete type is advantageous and beneficial compared to conventional concrete since it can lessen the number of skilled laborers, accelerates the project schedules, and reduce the noise pollution produced by mechanical vibrators. Thus, the concepts of SCC and HPC can be combined to produce concrete that can meet the performance requirements of self-consolidating with good durability and high compressive strength called self-consolidating high-strength concrete (SCHPC). Thus, realising these goals, the SCHPC usually needs a high amount of cementitious materials with a low water/binder ratio and smaller aggregates [24].

POFA has been utilised widely in normal grade concrete and innovatively in SCHSC and SCHPC. The contribution of POFA in SCHSC achieves a result range of 60–75 MPa at 28 days compressive strengths, as well as a good slump flow result range of 700–730 mm, which is compatible with the EFNARC standard [25]. A study by [26] on SCHPC with the utilisation of POFA indicates excellent workability in terms of filling ability, passing ability, and segregation resistance. However, there is no further research regarding the use of POFA in SCHPC, and regardless of the innovation of SCHPC, it has never been used with nano-size POFA.

This paper aims to highlight the potential utilisation of POFA as a nano-filler to produce a self-compacting high-performance concrete that is evaluated through workability and strength examination. The effects of nanosized POFA as cement replacement to concrete were investigated. Its performance is assessed based on the fresh and hardened properties such as flow table test and compressive strength test, which then compare to the control concrete.

EXPERIMENTAL DETAILS

Sample preparation

This study highlighted the potential of NaPOFA as cement replacement in the concrete with different levels percentage at 0%, 1%, 3%, 5%, 7%, and 10%. Six (6) different mixes were prepared; SCHPC, SCHPCNP1, SCHPCNP3, SCHPCNP5, SCHPCNP7, and SCHPCNP10.

In this study, the materials and samples of the specimen used are 50 mm concrete cubes, Ordinary Portland Cement, POFA, water, and glenium as an admixture. The Ordinary Portland cement is obtained from Tasek Corporation Sdn. Bhd. Since POFA is used as a cement replacement, each mixing used a different weight of cement. POFA used in this study is obtained from the incinerated palm oil waste from the United Palm Oil SDN BHD factory at Sungai Kecil, Nibong Tebal, Pulau Pinang, Malaysia. After collection, the raw POFA is oven dried for 24 hours to remove the excessive water. Next, POFA is sieved passing 212µm size to remove the coarse particles as small particles used for better control over the filler effect. After that, the sieve POFA underwent a milling process into the High Energy Milling machine along with 10 mm size of zirconium ball for 12 hours to formed NaPOFA. Potable tap water used in this study for concrete mixing is BS EN 1008, 2002.

Since there was no direct or standard design for the SCHPC mix, a slight modification was applied to previous research. The mix proportion used in this study refers to the concrete design mix in [27] research. The amount of cement used in producing ultra-high-performance concrete is between 700 and 1100 kg/m^3, about three times higher than the ordinary concrete [28]. The design mix was chosen for reference since it can produce high-performance concrete using normal coarse and fine aggregate, which is cheaper and easily available material in Malaysia. Normally, using a high amount of cement resulting in thermal cracking and low water content can reduce the workability of concrete. However, the superplasticizer used in this study contains polycarboxylate ether polymers, which can work with a low water-cement ratio and still obtain extended slump retention, improving the dimension stability and reduced the risk of the crack due to low shrinkage and creep. The superplasticizer used for this study is supplied by BASF (M) type MasterGlenium ACE 8538. Based on the studies from the previous researcher [21]-[22], 10% of POFA is used as the maximum percentage of cement replacement in their study. Therefore, the mix design was prepared with incorporation of 0%, 1%, 3%, 5%, 7%, and 10% of NaPOFA as partial replacement to cement. The sample preparation of the concrete used for this study is based on the design mix tabulated in Table 1.

Table 1: SCHPC Design Mix

Mix Designation	Material kg/m^3					
	Cement	Coarse Aggregate	Fine Aggregate	Water	Admixture	POFA
SCHPC	1000	800	433	200	16	-
SCHPCNP1	990	800	433	200	16	10
SCHPCNP3	970	800	433	200	16	30
SCHPCNP5	950	800	433	200	16	50
SCHPCNP7	9930	800	433	200	16	70
SCHPCNP10	900	800	433	200	16	100

Whereas for the mixing method, SCHPC design mix requires a different procedure compare to normal concrete. Firstly, the cement and POFA are mixed together in the mixer. Then, potable tap water is poured into the mixer and the superplasticizer and mixed for a specific time until a consistent cement paste is formed. After a consistent cement paste is formed, fine aggregate is poured into the mix, followed by coarse aggregate. Then, the mixture is left for several minutes for the concrete to be well mixed. After a well-mixed concrete is achieved, a flow test is conducted immediately, and the rest of the concrete is poured into a 50mm cube mould.

The hardened concrete cubes are cured for 1, 3, 7, 14, and 28 days. Before conducting the compressive strength test, the concrete cubes are removed from the tank and dry under the sun for at least two hours. Three samples were used in this study to take an average strength. The numbers of a sample are tested for compressive strength is shown in Table 2.

Table 2: Number of Samples for Compressive Strength

Mix Designation	Day				
	1	3	7	14	28
SCHPC	3	3	3	3	3
SCHPCNP1	3	3	3	3	3
SCHPCNP3	3	3	3	3	3
SCHPCNP5	3	3	3	3	3
SCHPCNP7	3	3	3	3	3
SCHPCNP10	3	3	3	3	3

Experimental Testing

The experimental testing comprised two tests: flow table and compression test. The flow table test was used to determine the workability of fresh concrete. The workability of concrete was determined as the percentage of nano POFA in the cement weight increased. Firstly, a layer of the concrete mix was placed 25 mm in thickness in the mould and tamp 20 times with the tamper. Then, run the machine 25 times in 15 s. The apparatus used are flow table, mould, tamper, and scale for measurement. The test was carried out using a flow table test machine in the concrete laboratory of the School of Civil Engineering, College of Engineering, Universiti Teknologi MARA. This flow table test is conducted with ASTM C 230-97 as reference.

Three (3) identical cubes of 50mm from each mix designated with a total of 90 hardened concrete cube samples were produced to assess the strength performance through compressive strength test at days 1, 3, 7, 14, and 28 ages of testing. The cubes were cured for 28 days in a curing pond using tap water at ambient temperature. The test was carried out using a compression machine in the concrete laboratory of the School of Civil Engineering, College of Engineering, Universiti Teknologi MARA. The compression test is conducted with ASTM C109 as a reference.

RESULTS AND DISCUSSION

Flow Table Test

The average flow diameter of six (6) series of concrete mixes is shown in Figure 1. Figure 1 shows the average flow diameter for concrete containing different percentages of NaPOFA designated as SCHPCNP1, SCHPCNP3, SCHPCNP5, SCHPCNP7, and SCHPCNP10. The graph shows that the plain SCHPC and SCHPCNP1 have the same result with the highest average diameter flow marked 250 mm, followed by SCHPCNP3, SCHPCNP5, SCHPCNP7, and SCHPCNP10 recorded flow 249 mm, 248 mm, 248 mm, and 247 mm, respectively. These results show that the concrete containing 3% of POFA designated as SCHPCNP3 corresponding to plain SCHPC shows a 0.4% decrement inflow. It was observed that the flow gradually depreciates as NaPOFA content increases. The flow is not affected by the W/C ratio of concrete. It is because the cement in the concrete is partially replaced. Hence, the binder content is still the same. However, the flow is affected by the content of POFA replacing the cement. The use of a high amount of POFA as cement replacement will decrease workability because POFA contains a high content of non-burning carbon [29]. Besides, the nature of POFA, which is irregular in shape and porous structure, absorbed more water and decreasing in workability of the concrete [30]. Thus, SCHPC and SCHPCNP1 are shown to inhibit the best flow percentage among concrete samples.

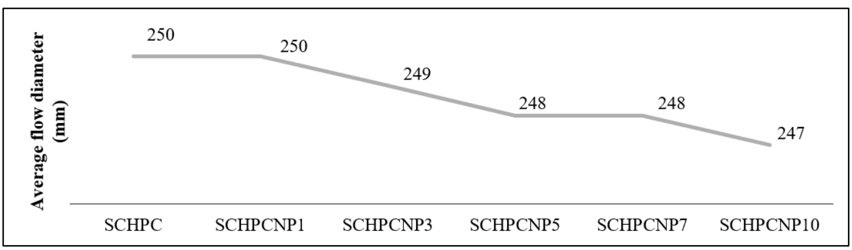

Figure 1: Average Flow Diameter of Six (6) Series of Concrete Mixes Incorporating Different Content of NaPOFA Replacement

Compressive Strength Test

The compressive strength of six (6) series of concrete mixes is shown in Figure 2. Figure 2 shows the effect of NaPOFA inclusion as cement replacement on the compressive strength for the concrete for days 1, 3, 7, 14, and 28. It shows that the compressive strength of the concrete of SCHPCNP1 gives the higher result on compressive strength for 28 days, followed by SCHPC, SCHPCNP3, SCHPCNP5, SCHPCNP7, and SCHPCNP10. It exhibits that the compressive strength developed as 1% of NaPOFA used as cement replacement in concrete. The increase in the compressive strength is due to the production of secondary C-S-H gels via pozzolanic reactions in nanoparticles and the ability of POFA to act as filler which contributed to the enhancement of its mechanical properties [16].

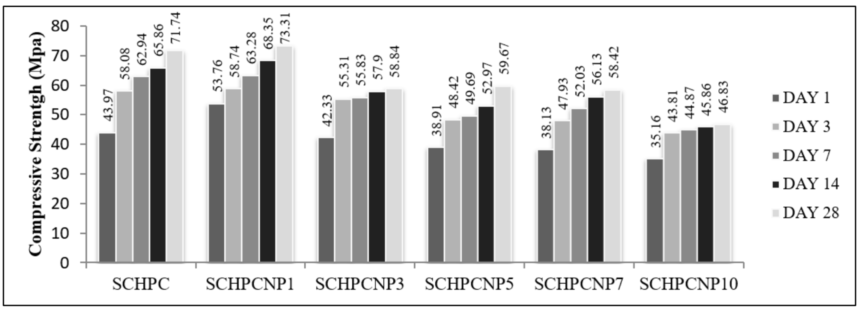

Figure 2: Compressive Strength of Six (6) Series of Concrete Mixes Incorporating Different Content of NaPOFA

However, the higher percentage of POFA used as a cement replacement, decreasing the compressive strength. It shows that NaPOFA as cement replacement optimizes further up to 1%. The high porosity in the POFA particles causes an increase in the water-to-binder ratio of concrete, resulting in a lower compressive strength [7]. This is also proven by [9, 12, 13], where all of the concrete compressive strength decreased as POFA replacement increased. On the other hand, a study by [6] shows that specimens incorporated with more nano POFA resulted in lower compressive strength than OPC due to less cement needed to develop the strength, which is interrupted by nano POFA hydration.

The graph shows that the increment of strength between SCHPCNP1 and SCHPC is only up to 2%. However, SCHPNP1 shows better early strength than SCHPC, with a 22% increment on day one. Comparing all the data, SCHPCNP1 achieved the targeted high strength concrete requirement, above 50 MPa at only day 1, whereas SCHPC achieved on day 3. This type of concrete can speed up the construction time. Thus, improving the efficiency in the construction industry.

Relationship of the Slump and Compressive Strength of Concrete

Based on the data obtained from the average flow diameter and compression test conducted, a relationship is made, as shown in Figure 3. By incorporating both the flow and compressive strength, a relationship between the two (2) properties is identified to find the best concrete mix. From Figure 3, all mixes show the same results for workability. As seen in Figure 3, SCHPCNP3, SCHPCNP5, SCHPCNP7, and SCHPCNP10 mix are shown to inhibit low compressive strength and flow. SCHPC tends to have the highest flow but slightly low compressive strength compared to the SCHPCNP1 mix. SCHPCNP1 mix, on the other hand, inhibits the highest compressive strength with the same result of flow with SCHPC. Since the goal of this stage is to obtain the highest strength and excellent flow, therefore the mix that inhibits that property is SCHPCNP1. Other than that, SCHPCNP1 also shows better early compressive strength than SCHPC, thus making it the best mix for this research.

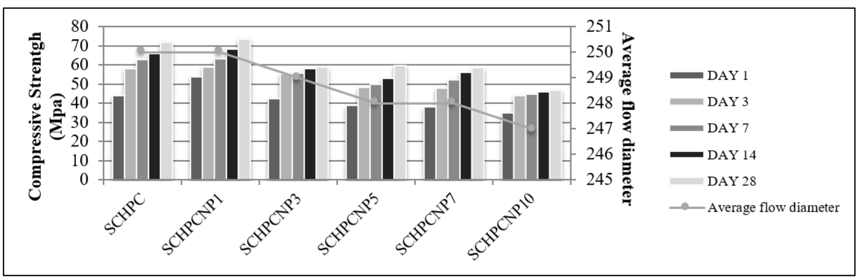

Figure 3: Relationship Between Average Flow Diameter and Compressive Strength of Six (6) Series of Concrete Mixes Incorporating Different Content of NaPOFA as Cement Replacement

CONCLUSION

This study emphasizes the flow, compressive strength, and the relationship between these concrete properties incorporated with NaPOFA as cement replacement through experimental investigation. Based on the experiment conducted throughout this study, the final analysis is as follows;

1. The utilisation of a high amount of NaPOFA as cement replacement in concrete contributes to reducing its average flow diameter. This is due to the POFA that contains a high content of non-burning carbon and its porous nature, which absorbed more water than cement. This study shows that the utilisation of 1% of NaPOFA produces excellent flow similar to control concrete.
2. Using a certain amount of NaPOFA as cement replacement in concrete tends to enhance the compressive strength performance. However, as the percentage of cement replacement NaPOFA increases, the compressive strength is reduced due to less cement for strength development. From this study, SCHPCNP1 gives the highest result on compressive strength, and it concludes that 1% of NaPOFA is the optimum percentage to be used as a cement replacement that will produce concrete with the best compressive strength.
3. Based on the relationship between flow and compressive strength test, the concrete with the best performance can be obtained. SCHPCNP1 is the best design mix because it has flow behaviour similar to control concrete yet slightly higher compressive strength. Additionally, SCHPCNP1 also shows better early strength on day 1 compared to control.

Therefore, SCHPCNP1 is suitable for use in construction since it could speed up and improve the efficiency of construction work. The excellent workability of SCHPCNP1 accelerates the construction process since no mechanical vibration machine is needed to fill up the formwork. Other than that, the early strength possesses by SCHPCNP1 could help in the early erection of formwork so that other construction work can proceed quickly. Thus, SCPCNP1 is advantageous in terms of construction efficiency, sustainability, and economy.

ACKNOWLEDGEMENTS

The author would like to acknowledge the Research Management Centre (RMC) for the financial support granted under 600-IRMI/FRGS 5/3 (176/2019) and 600-RMC/GIP 5/3 (032/2021). Also, the author is indebted to the lab technicians at the Material and Heavy Structural Lab of the School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, Selangor Darul Ehsan for their guidance with the laboratory work. Besides, special thanks to the Institute for Infrastructure Engineering and Sustainable Management (IIESM) and School of Civil Engineering, College of Engineering, Universiti Teknologi Mara (UiTM) for providing the facilities to accomplish the laboratory work throughout this research.

REFERENCES

[1] M. J. Iskandar, A. Baharum, F. H. Anuar, and R. Othaman, "Palm oil industry in South East Asia and the effluent treatment technology—A review," *Environ. Technol. Innov.*, vol. 9, no. May 2017, pp. 169–185, 2018, DOI: 10.1016/j.eti.2017.11.003

[2] Malaysian Palm Oil Board, "Overview of the Malaysian Oil Palm Industry," 2020. DOI: 10.1017/CBO9781107415324.004

[3] S. O. Bamaga, M. W. Hussin, and M. A. Ismail, "Palm Oil Fuel Ash: Promising supplementary cementing materials," *KSCE J. Civ. Eng.*, vol. 17, no. 7, pp. 1708–1713, 2013, DOI: 10.1007/s12205-013-1241-9

[4] N. M. Altwair and S. Kabir, "Palm Oil Fuel Ash(POFA): An Environmental-Friendly Supplemental Cementitious Material For Concrete Production," *Int. RILEM Conf. Mater. Sci.*, vol. III, no. January 2010, pp. 113–126, 2010

[5] V. S. Ahamed and S. Siddiraju, "Study of Strength of Concrete with Palm Oil Fuel Ash as Cement Replacement," *Int. J. Civ. Eng. Technol.,* vol. 7, no. 3, pp. 337–341, 2016

[6] K. Wi, H. S. Lee, S. Lim, H. Song, M. W. Hussin, and M. A. Ismail, "Use of an agricultural by-product, nano sized Palm Oil Fuel Ash as a supplementary cementitious material," *Constr. Build. Mater.*, vol. 183, pp. 139–149, 2018, DOI: 10.1016/j.conbuildmat.2018.06.156

[7] M. R. Karim, M. F. M. Zain, M. Jamil, and M. N. Islam, "Strength of Concrete as Influenced by Palm Oil," *Aust. J. Basic Appl. Sci.*, vol. 5, no. 5, pp. 990–997, 2011

[8] M. W. Hussin, M. A. Ismail, A. Budiea, and K. Muthusamy, "Durability of High Strength Concrete Containing Palm Oil Fuel Ash of Different Fineness," *Malaysian J. Civ. Eng.,* vol. 21, no. 2, pp. 180–194, 2009

[9] M. Safiuddin, M. A. Salam, and M. Z. Jumaat, "Utilization of palm oil fuel ash : A review," *J. Civ. Eng. Manag.*, vol. 17, no. 2, pp. 234–247, 2011, DOI: 10.3846/13923730.2011.574450

[10] P. Chindaprasirt, S. Rukzon, and V. Sirivivatnanon, "Effect of carbon dioxide on chloride penetration and chloride ion diffusion coefficient of blended Portland cement mortar," *Constr. Build. Mater.*, vol. 22, no. 8, pp. 1701–1707, 2008, DOI: 10.1016/j.conbuildmat.2007.06.002

[11] H. M. Hamada, F. M. Yahaya, K. Muthusamy, G. A. Jokhio, and A. M. Humada, "Fresh and hardened properties of palm oil clinker lightweight aggregate concrete incorporating Nano-palm oil fuel ash," *Constr. Build. Mater.,* vol. 214, pp. 344–354, 2019, DOI: 10.1016/j.conbuildmat.2019.04.10

[12] V. Sata, C. Jaturapitakkul, and K. Kiattikomol, "Utilization of Palm Oil Fuel Ash in High-Strength Concrete," *J. Mater. Civ. Eng.,* vol. 16, no. 6, pp. 623–628, 2004, DOI: 10.1061/(ASCE)0899-1561(2004)16:6(623)

[13] W. Tangchirapat, T. Saeting, C. Jaturapitakkul, K. Kiattikomol, and A. Siripanichgorn, "Use of waste ash from palm oil industry in concrete," *Waste Manag.*, vol. 27, no. 1, pp. 81–88, 2007, DOI: 10.1016/j.wasman.2005.12.014

[14] A. M. Zeyad, M. A. Megat Johari, B. A. Tayeh, and M. O. Yusuf, "Pozzolanic reactivity of ultrafine palm oil fuel ash waste on strength and durability performances of high strength concrete," *J. Clean. Prod.*, vol. 144, no. October 2017, pp. 511–522, 2017, DOI: 10.1016/j.jclepro.2016.12.121

[15] H. M. Hamada, G. A. Jokhio, F. M. Yahaya, and A. M. Humada, "Applications of Nano palm oil fuel ash and Nano fly ash in concrete," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 342, no. 1, 2018, DOI: 10.1088/1757-899X/342/1/012068

[16] M. A. A. Rajak, Z. A. Majid, and M. Ismail, "Morphological Characteristics of Hardened Cement Pastes Incorporating Nano-palm Oil Fuel Ash," *Procedia Manuf.*, vol. 2, no. February, pp. 512–518, 2015, DOI: 10.1016/j.promfg.2015.07.088

[17] R. Jagana and C. V. Vinod, "High Strength Concrete," *Int. J. Eng. Sci. Res. Technol.*, vol. 6, no. 3, pp. 207–209, 2017

[18] M. A. Ismail, A. M. A. Budiea, M. W. Hussin, and K. B. Muthusamy, "Effect of POFA fineness on durability of high strength concrete," *Indian Concr. J.*, vol. 84, no. 11, pp. 21–28, 2010

[19] B. Alsubari, P. Shafigh, and M. Z. Jumaat, "Utilization of high-volume treated palm oil fuel ash to produce sustainable self-compacting concrete," *J. Clean. Prod.*, vol. 137, pp. 982–996, 2016, DOI: 10.1016/j.jclepro.2016.07.133

[20] M. Safiuddin, M. A. Salam, and M. Z. Jumaat, "Key Fresh Properties of Self-Consolidating High-Strength POFA Concrete," *J. Mater. Civ. Eng.,* vol. 26, no. 1, pp. 134–142, 2013, DOI: 10.1061/(asce)mt.1943-5533.0000782

[21] 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," *J. Clean. Prod.*, vol. 115, pp. 307–314, 2015, DOI: 10.1016/j.jclepro.2015.12.051

[22] J. Tay, "Ash from Oil-Palm Waste as Concrete Material," *Journal of Materials in Civil Engineering.,* vol. 2, no. 2, pp. 94–105, 1990

[23] P.-C. Aïtcin, *Binder for Durable and Sustainable Concrete*. London: Taylor & Francis, 2008

[24] A. M. Matos, L. Maia, S. Nunes, and P. Milheiro-Oliveira, "Design of self-compacting high-performance concrete: Study of mortar phase," *Constr. Build. Mater*., vol. 167, pp. 617–630, 2018, DOI: 10.1016/j.conbuildmat.2018.02.053

[25] B. Alsubari, P. Shafigh, and M. Z. Jumaat, "Development of self-consolidating high strength concrete incorporating treated palm oil fuel ash," *Materials (Basel)*., vol. 8, no. 5, pp. 2154–2173, 2015, DOI: 10.3390/ma8052154

[26] M. Adamu and N. Bala, "Performance of Self-Consolidating High Performance Ternary Blended Concrete," *Noble Int. J. Sci. Res*., vol. 1, no. 2, pp. 44–49, 2017

[27] M. S. M. Norhasri, M. S. Hamidah, and A. M. Fadzil, "Inclusion of nano metaclayed as additive in ultra high performance concrete (UHPC)," *Constr. Build. Mater*., vol. 201, pp. 590–598, 2019, DOI: 10.1016/j.conbuildmat.2019.01.006

[28] M. Bandukwala and H. G. Sonkusare, "Study of Reactive Powder Concrete and its Characteristics," *Int. J. Sci. Technol. Eng*., vol. 2, no. 07, pp. 77–79, 2016

[29] H. M. Hamada, G. A. Jokhio, F. M. Yahaya, A. M. Humada, and Y. Gul, "The present state of the use of palm oil fuel ash (POFA) in concrete," *Constr. Build. Mater*., vol. 175, pp. 26–40, 2018, DOI: 10.1016/j.conbuildmat.2018.03.227

[30] S. K. Lim, C. S. Tan, O. Y. Lim, and Y. L. Lee, "Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler," *Constr. Build. Mater*., vol. 46, pp. 39–47, 2013, DOI: 10.1016/j.conbuildmat.2013.04.015