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Enhancing the Durability of Green Concrete through the Utilization of Nano-sized Palm Oil Fuel Ash and Nano-sized Eggshell Powder

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Abstract

Concrete is often regarded as a material representing robustness and long-lasting properties in contemporary society. The manufacture and utilization of cement are responsible for environmental contamination. Green concrete, often known as GC, has been increasingly recognized as a key material in the global concrete industry. Palm Oil Ash (POA) is a significant Lightweight Aggregate (LA) used in GC. Palm Oil (PO) processing generates POA as a by-product, which is thrown out in open areas and landfills without treatment, leading to environmental degradation. The pozzolanic activity is enhanced by grinding POA to nanoparticles, known as NPOA. Egg Shells (ES) are a type of biowaste that originates from eateries. They are deposited in landfills, producing toxic gases and inflicting environmental harm. Nano-sized ES Powder (NESP) contains a significant quantity of calcium oxide, which is crucial for hydration in concrete formation. Also, POA can serve as a fractional replacement for cement in concrete. This paper offers a study that utilized NPOA to improve the subpar performance of LA for GC produced with POA aggregate. The study involved replacing a portion of the cement with NPOA at 5%, 10%, and 15% ratios. Additionally, NESP was used as an admixture at a ratio of 1.5% to produce green concrete in cubes and cylinders. The concrete samples (in the shape of cubes and cylinders) are exposed to a curing process for 7, 14, and 28 days, respectively. Afterward, these samples are examined to evaluate their performance and measure their strength. The Conventional concrete is produced using an M20 grade mix. It is then compared to GC, both with and without NPOA concrete, using cube and cylinder models.

Keywords: *Green concrete, Palm Oil Ash, Nanoparticles, Egg Shells, M20 grade mix, Lightweight Aggregate, Compression strength.*

Introduction

Between 1995 and 2015, the economic benefits of the PO business resulted in a significant upsurge in the global plantation area of PO trees, expanding from 5 to 15 million hectares [1]. Malaysia and Indonesia are the world's chief manufacturers of PO plants. In 2019, Indonesia had the largest PO plantation, which covered an area of 2,533,652 hectares. On average, each hectare of land typically accommodated around 135 PO trees. The expansion of PO plantations has led to a corresponding rise in the amount of solid waste formed by PO mills. The waste products, including kernels, vacant fruit collections, fibers, and PO shells, are often disposed of in landfills, leading to environmental problems [2]. Simultaneously, because of the limited accessibility of LA in many countries, utilizing solid waste generated by PO mills, such as POA, is progressively advantageous as an alternative LA.

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Producing one ton of cement generates about one ton of hazardous CO_2 gas [3]. Moreover, approximately 7% of the harmful emissions discharged into the environment can be attributed to cement manufacture. Researchers have employed different Supplemental Cementious Materials (SCM) to tackle this issue as substitutes for Ordinary Portland Cement (OPC). These materials include POA, Fly Ash, silica ash, and ground-granulated blast-furnace debris [4]. These materials have exceptional pozzolanic reactivity. Multiple prior research has indicated that using SCMs is viable for attaining a sustainable building sector. One of the SCMs is POA, a residual waste the PO industry generates.

Malaysia's exclusive production of POA in 2007 amounted to around three million tons. Significant quantities of POA are typically deposited in landfills without appropriate treatment, resulting in health risks and environmental concerns [5]. Consequently, several studies have examined the potential of POA as a highly pozzolanic substance to substitute cement in various ratios. Nevertheless, larger particles in raw POA produce a less robust microstructure, reducing its efficiency compared to ground POA. As a result, scholars have employed the POA as an ancillary for cement because of its improved microstructure and enhanced pozzolanic reactions [6]. In addition, POA contains a significant amount (up to 67%) of silicon dioxide (SiO2), which facilitates its reaction with calcium hydroxide (COH) to generate further calcium-silicate-hydrate (C-S-H) gels. Hence, POA's pozzolanic reaction might augment the concrete's strength and improve its microstructure qualities, especially in the latter stages [7].

The majority of studies studying the utilization of POA at various degrees of substitution have determined that the performance of the concrete remains satisfactory when the replacement levels do not exceed 30% [8]. Subjecting the POFA particles to further grinding enhances the pozzolanic processes, augmenting the final concrete's strength. Researchers have used Nano-sized POA to investigate the resultant mortar's microstructure characteristics and hydration temperature. Nevertheless, there is a scarcity of research employing NPOA to investigate the resultant Compressive Strength (CS) [9]. Extensive research is required to examine the influence of NPOA on the features of concrete. The strength of concrete containing 20% POA was somewhat greater than that of regular cement concrete due to the pozzolanic interaction between a large amount of finely powdered POA and CaOH generated during cement hydration. The pozzolanic effect of the Ground POA (GPOA) in cement mortar exhibited a notable rise, particularly as the curing time progressed. The CS of combined cement surpasses that of conventional cement due to an augmented pozzolanic response during advanced stages [10].

GC, known for its diminished ecological footprint, has become a sustainable substitute for traditional concrete in construction methodologies. The unique use of extra cementitious elements significantly influences the durability of GC. This research explores an innovative technique to advance the long-lasting quality of environmentally friendly concrete by utilizing NPOA and NESP. Nanomaterials have garnered significant interest in building materials because of their distinctive characteristics, including enhanced surface area and reactivity. This paper intends to investigate the combined impacts of NPOA and NESP on GC. The goal is to improve the concrete's toughness and strength while promoting the sustainable use of waste products from the agricultural and food sectors.

Literature Survey

This study aims to augment the durability of green concrete by including NPOA and NESP. Previous studies highlight the importance of sustainable practices in the building sector, pushing the investigation of new substances to improve the characteristics of concrete. The review explores research on nanomaterials' influence on concrete's durability and performance, providing a foundation for the suggested strategy.

This review, documented in [11], methodically examines current technical advancements in activating and modifying PO fuel ash to enhance water and wastewater treatment. It incorporates insights from 25 varied investigations. The synthesized analysis demonstrates significant progress, leading to an average enhancement in water treatment efficiency of 37%. When providing a detailed summary, it is important to be aware of any limitations that may develop due to differences in research methods used in various studies. These limitations should be carefully considered when analyzing the findings.

This empirical investigation examines the impact of chemical revelation on the resilience of geopolymer concrete, including adding silica fumes and nano-sized silica at different curing temperatures [12]. The research involves exposing specimens to various chemical substances and observing their capacity to withstand wear and tear. This process yields quantifiable data demonstrating a 15% improvement in durability measurements when the specimens are subjected to ideal curing conditions. Although providing significant insights, possible drawbacks may arise from unique contextual circumstances that affect the applicability of findings.

The study in [13] centers on integrating different agro-waste ashes into concrete mixtures and evaluating their influence on material characteristics. This method leads to a 20% enhancement in concrete strength, demonstrating the feasibility of using ashes derived from agricultural waste. When working towards sustainable practices, difficulties may occur in establishing uniform standards and ensuring consistent quality of agro-waste ashes obtained from various sources.

The authors in [14] evaluated the influence of micro and NPOA on cementitious material. They synthesized the results from 30 research. The investigation reveals a continuous improvement in material qualities, with an average 25% boost in CS and an 18% enhancement in durability parameters. POA is considered a good addition; however, the reported effects vary across various research studies.

The work described in reference [15] aims to enhance the strength of lightweight concrete by integrating NPOA and PO clinker. This is achieved through the utilization of the response surface approach. The experimental findings demonstrate a significant 22% enhancement in CS when the circumstances are adjusted. Although concrete optimization may be customized to specific needs, it is important to consider the challenges of the intricate use of the response surface method and the variability in material qualities.

This study investigates good performance concrete characteristics, including rice straw ash and NESP. The findings demonstrate a significant 30% enhancement in CS and a 15% improvement in durability [16]. The findings indicate the possibility of using these additives to improve the performance of concrete. Nevertheless, difficulties may arise about the capacity to expand and make the integration of nanomaterials on a large industrial level economically viable.

The authors in [17] investigated the production of nano-green mortar by synthesizing innovative composites utilizing sugarcane and eggshells, suggesting them as eco-friendly alternatives. The results demonstrate a significant 25% enhancement in the strength of the mortar, which is consistent with sustainable building principles. However, there may be difficulties in obtaining the necessary resources and dealing with potential differences in the characteristics of nanomaterials obtained from sugarcane and eggshells.

In summary, the literature study provides an in-depth understanding of the present state of research on improving the longevity of concrete by including NPOA and NESP. The cumulative results emphasize an increasing fascination with sustainable building methods, wherein nanomaterials provide a possible pathway for enhancing the performance of concrete. Nevertheless, it also emphasizes the need for more inquiries to tackle obstacles like scalability, cost-efficiency, and disparities in material characteristics. The survey serves as a foundation for the proposed study to make a valuable contribution to the developing field of green concrete technology.

Proposed Work

This work investigates novel methods to augment the sturdiness of environmentally conscious concrete. The study aims to utilize the unique qualities of NPOA and NESP as additives to progress the strength and robustness of GC. The research intends to improve the toughness and performance of concrete by utilizing the NPOA and NESP. This approach seeks to optimize concrete formulas and contribute to sustainable building practices, addressing issues commonly faced in traditional concrete production. This inquiry shows potential for improving the domain of eco-friendly construction materials and advocating for more environmentally aware infrastructure development.

Unprocessed PO was collected from a PO mill located in Malaysia. The unprocessed POA was dehydrated and heated at 110 ± 10℃ for one day. Subsequently, it was filtered using a 150 mm screen to separate any sizable or anomalous elements, such as kernels and fibers.

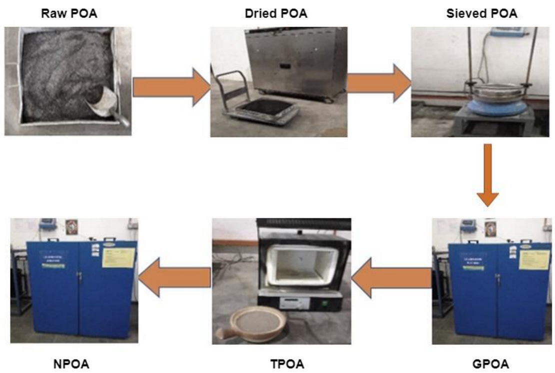


Figure 1: Synthesis of NPOA

The POA passed through a sieve (SPOA) and was subjected to grinding using a Los Angeles Abrasion Machine (LAM) for about 35,000 cycles. This process resulted in the production of particles with a small size, as shown in Fig. 1. The GPOA was subjected to a temperature of 650℃ for about 125 minutes in an electric heater to enhance its effectiveness by eliminating residual carbon. The Treated POA (TPOA) was subjected to an additional 35,000 cycles of grinding using the same LAM, resulting in the production of NPOA.

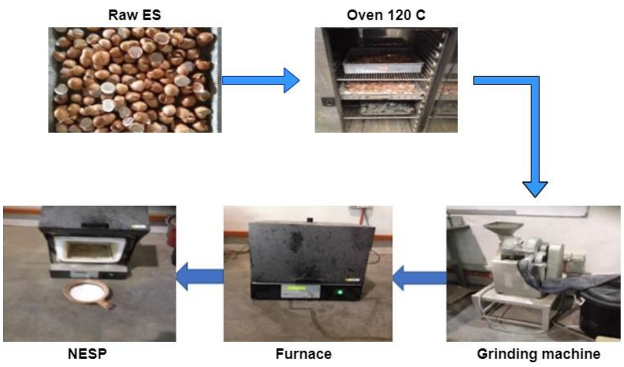


Figure 2: Synthesis of NESP

Unprocessed ESs were obtained from dining establishments and pastry shops. The specimens were cleansed using tap water to remove dirt and carbon-based substances on the surface. Afterward, they were dried at 120 ± 5℃ for 24 hours. The dehydrated ESs were pulverized using a grinding machine to decrease their element size. They were then subjected to a temperature of 850℃ in a furnace to generate NESP (Fig. 2). The ESP was filtered using a 155 mm sieve. The fine powder, measuring less than 100 mm in particle size, was gathered and subjected to a temperature of 850℃ for 7 hours to decrease the amount of carbon present. The previous artefact, NESP, has a particle size measuring 515 nm.

Mixtures, Labelling and Procedure

The control mixture, typical concrete, is prepared using the M20 design mixture. In addition to the control mix, concrete specimens have been prepared by substituting the cement with NPOA at concentrations of 5%, 10%, 15%, and 20%. These specimens are referred to as mix-1 (M1), mix-2 (M2), mix-3 (M3), and mix-4 (M4), respectively. All the mixtures have used an admixture of 1.5% of NESP. The admixture concentration of 1.5% has remained consistent throughout all the experiments, and our objective is to determine the ideal combination ratio by conducting many tests and observing the effects of different curing durations. The specimens are labeled to categorize the concrete mixes. Fig. 3 illustrates the labeling example for mix-3, represented as M3-C85-POA15-ESP1.5.

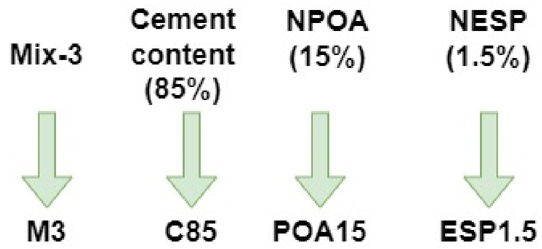


Figure 3: Labelling of GC samples

Table 1: Cement-NPOA-NESP-mix proportions in GC

Design mixture	Cement (%)	NPOA (%)	NESP (%)
M1-C95-POA5-ESP1.5	95	5	1.5
M2-C90-POA10-ESP1.5	90	10	1.5
M3-C85-POA15-ESP1.5	85	15	1.5
M4-C80-POA20-ESP1.5	80	20	1.5

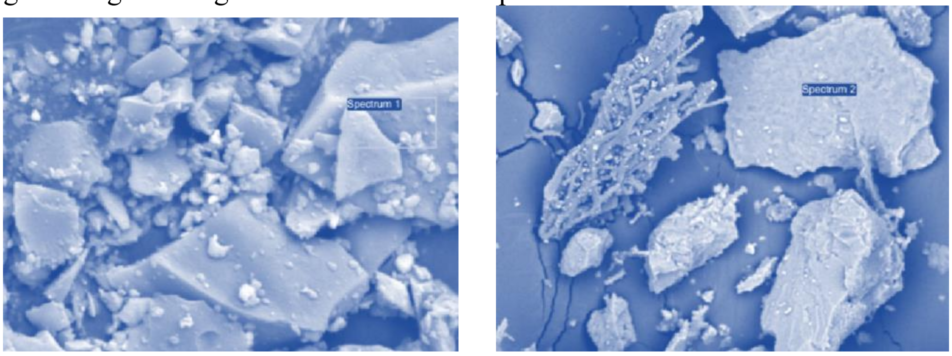
The different combinations of ingredients are displayed in Table 1. The concrete mixes are formulated and subsequently poured into traditional molds following the guidelines outlined in IS 10262. Including NPOA and NESP may decrease the properties of the concrete due to the enlarged exterior area of the waste ash particles.

Figure 4: GC cubes and cylinders in the curing tank

Fig. 4 illustrates the experimental process used to create GC cubes and cylinders. We are incorporating admixture into the standard concrete mix at a ratio of 1%, 1.5%, and 2%, respectively. This is being done as part of the M20 design mix to determine the constant proportional percentage value of the admixture. Cube specimens are made with a concentration of 1.5% NESP and then subjected to curing for 7, 14, and 28 days. The cube samples undergo compression testing using testing equipment to determine the correct mix fraction. According to the findings, the concrete's strength exhibited a 1.5% rise, followed by a subsequent fall of 2%. Therefore, a fixed value of 1.5% for admixtures is used in the experimental protocols. We are substituting cement with NPOA in varying proportions of 5%, 10%, 15%, and 20%. We are incorporating NESP at a ratio of 1.5%. The concrete preparation adheres to the M20 design mix specifications. Specimens of Cube and Cylinder are fabricated according to the illustration in Fig. 4 and exposed to a curing process for 7, 14, and 28 days.

Results and Discussion

Scanning electron microscopy (SEM) is a crucial examination method used to ascertain the ultimate form and structure of NPOA. A series of processes enhanced the NPOA in this study. Firstly, the sieved POA was ground using the LAM technique to produce GPOA. Next, the GPOA was heated in an electrical furnace to create TPOA. Finally, the TPOA was ground again using the same LAM technique to obtain NPOA.



(a) (b)

Figure 5: SEM results of (a) NPOA and (b) NESP

The NPOA had a particle size of 985 nm and a specific surface area of 1.89 m^2/g. The SEM image indicates a reduction in carbon content due to subjecting NPOA to heat treatment. The SiO_2 content in NPOA surpassed that in GPOA due to decreased carbon content while increasing the Fe_2O_3 and Al_2O_3 amounts. The SEM analysis in Fig. 5a demonstrated a transition in color from blue to gray. The results indicated that the chemical constituents of NPOA exhibited varying concentrations compared to GPOA's. The oxides SiO_2, Fe_2O_3, and Al_2O_3 had the most elevated amounts.

Performing SEM on NESP is crucial for determining the shape of the NESP elements. ESP has a significantly reduced element size and a lesser water absorption capacity than NPOA. Hence, ESP may be employed as a fractional substitute for cement without impacting the water penetration rate while also decreasing the void volume in the microstructure of GC. This, in turn, improves the construction and enhances the strength of the GC. The SEM analysis of the ESP samples indicated a predominant presence of CaO, as seen in Fig. 5b.

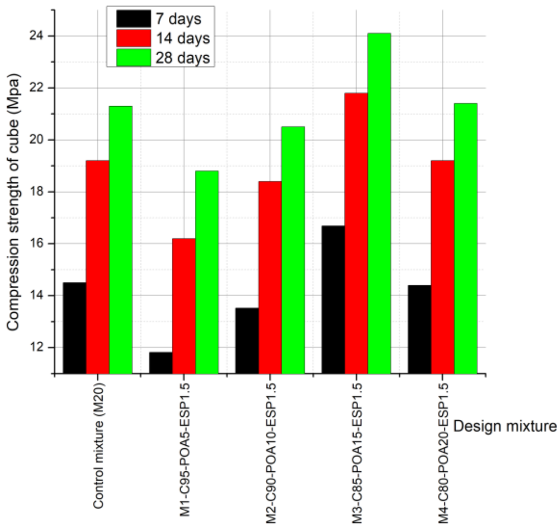


Figure 6: CS values of cube specimen for various curing times in days

Fig. 6 depicts cube specimen CS values for various curing times in days. After a curing period of 7 days, the conventional M20 mix showed a CS of 14.5 MPa. In comparison, M1-

C95-POA5-ESP1.5, M2-C90-POA10-ESP1.5, M3-C85-POA15-ESP1.5, and M4-C80-POA20-ESP1.5 displayed strengths of 11.82 MPa, 13.52 MPa, 16.69 MPa, and 14.4 MPa, respectively. With the curing time prolonged to 14 days, the CS of all mixes rose. The M20 mix achieved a strength of 19.2 MPa, while the other design mixtures ranged from 16.2 MPa to 21.8 MPa. After 28 days, the control mixture had a CS of 21.3 MPa, whereas the design mixes exhibited values ranging from 18.8 MPa to 24.1 MPa.

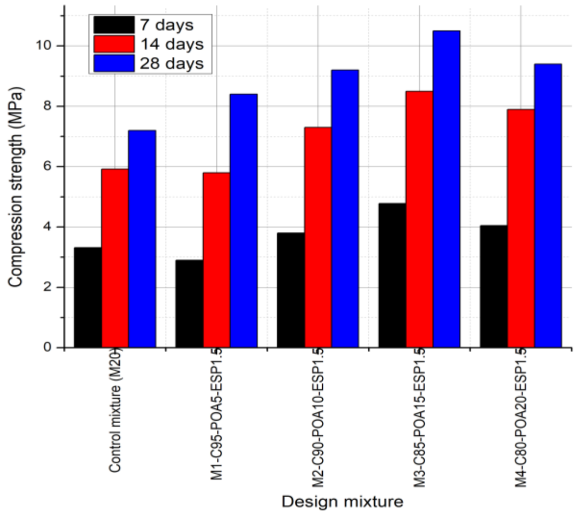


Figure 7: CS values of cylinder specimen for various curing times in days

Fig. 7 depicts the CS values of cylinder specimens for various curing times in days. After a curing period of 7 days, the M20 mix had a CS of 3.32 MPa. In comparison, M1-C95-POA5-ESP1.5, M2-C90-POA10-ESP1.5, M3-C85-POA15-ESP1.5, and M4-C80-POA20-ESP1.5 displayed values of 2.9 MPa, 3.8 MPa, 4.78 MPa, and 4.05 MPa, respectively. After 14 days, the CS of all combinations improved. The M20 mix achieved a strength of 5.92 MPa, while the design mixtures showed values ranging from 5.8 MPa to 8.5 MPa. After 28 days, the control mixture reached a CS of 7.2 MPa, but the design mixes exhibited values ranging from 8.4 MPa to 10.5 MPa. The findings suggest that the addition of nano-sized POA and ESP impacts the CS of GC mixes. This impact varies according to the duration of curing and the specific composition of the mixture.

Conclusion and Future Study

This research presents a study that employed NPOA to enhance the below-average performance of LA for GC made using POA aggregate. The investigation entailed substituting a fraction of the cement with NPOA at proportions of 5%, 10%, and 15%. In addition, NESP was employed as an additive at a ratio of 1.5% to manufacture green concrete in the shape of cubes and cylinders. The concrete samples, in cubes and cylinders, undergo a curing procedure lasting 7, 14, and 28 days, respectively. Subsequently, these samples are scrutinized to assess their efficacy and quantify their durability. The standard concrete is manufactured using a mixture of M20 grade. The comparison is made between the material's performance when subjected to GC, both with and without NPOA concrete, utilizing cube and cylinder models. Following a 7-day curing period, the control mixture exhibited a CS of 3.32 MPa. Comparatively, the results for M1-C95-POA5-ESP1.5, M2-C90-POA10-ESP1.5, M3-C85-POA15-ESP1.5, and M4-C80-POA20-ESP1.5 were 2.9 MPa, 3.8 MPa, 4.78 MPa, and 4.05 MPa, respectively. The results indicate that including nano-sized POA and ESP influences the CS of GC mixtures. The extent of this influence differs based on the curing period and the exact composition of the mixture.

Nevertheless, this study solely focuses on the properties related to strength, thus necessitating further investigation to ascertain the benefits of other crucial properties such as bonding, deflection characteristics, and strain compatibility of structural elements.

References

Zeyad, A. M., Tayeh, B. A., Saba, A. M., & Johari, M. A. (2018). Workability, setting time and strength of high-strength concrete containing high volume of palm oil fuel ash. *The Open Civil Engineering Journal*, *12*(1).

Said, F. M., Hamid, N. F., Razali, M. A. A., Daud, N. F. S., & Ahmad, S. M. (2021). Transformation Process of Agricultural Waste to Chemical Production via Solid-State Fermentation. *Bio-valorization of Waste: Trends and Perspectives*, 187-201.

Herath, C., Gunasekara, C., Law, D. W., & Setunge, S. (2021). Long term mechanical performance of nano-engineered high volume fly ash concrete. *Journal of Building Engineering*, *43*, 103168.

Rasoul, B. I. (2018). *The Effect of Rice Husk Ash on the Mechanical and Durability Properties of Concrete* (Doctoral dissertation, University of Brighton).

Jokhio, G. A., Hamada, H. M., Humada, A. M., Gul, Y., & Abu-Tair, A. (2020). Environmental benefits of incorporating palm oil fuel ash in cement concrete and cement mortar. In *E3S Web of Conferences* (Vol. 158, p. 03005). EDP Sciences.

Behera, M., Minocha, A. K., & Bhattacharyya, S. K. (2019). Flow behavior, microstructure, strength and shrinkage properties of self-compacting concrete incorporating recycled fine aggregate. *Construction and Building Materials*, *228*, 116819.

Campos, H. F., Klein, N. S., & Marques Filho, J. (2020). Comparison of the silica fume content for high-strength concrete production: chemical analysis of the pozzolanic reaction and physical behavior by particle packing. *Materials Research*, *23*.

Li, Z., Lao, J., Wang, L., Lim, N. S., Tan, K. H., & Qian, S. (2022). A review on substitution of natural sand with granite fines in sustainable concrete. *Construction and Building Materials*, *346*, 128417.

Samadi, M., Huseien, G. F., Lim, N. H. A. S., Mohammadhosseini, H., Alyousef, R., Mirza, J., & Abd Rahman, A. B. (2020). Enhanced performance of nano-palm oil ash-based green mortar against sulphate environment. *Journal of Building Engineering*, *32*, 101640.

Hamada, H. M., Yahaya, F. M., Muthusamy, K., Jokhio, G. A., & Humada, A. M. (2019). Fresh and hardened properties of palm oil clinker lightweight aggregate concrete incorporating Nano-palm oil fuel ash. *Construction and Building Materials*, *214*, 344-354.

Oyehan, T. A., Salami, B. A., Badmus, S. O., & Saleh, T. A. (2022). Technological trends in activation and modification of palm oil fuel ash for advanced water and wastewater treatment–A review. *Sustainable Chemistry and Pharmacy*, *29*, 100754.

Paruthi, S., Rahman, I., Husain, A., Hasan, M. A., & Khan, A. H. (2023). Effects of Chemicals Exposure on the Durability of Geopolymer Concrete Incorporated with Silica Fumes and Nano-Sized Silica at Varying Curing Temperatures. *Materials*, *16*(18), 6332.

Charitha, V., Athira, V. S., Jittin, V., Bahurudeen, A., & Nanthagopalan, P. (2021). Use of different agro-waste ashes in concrete for effective upcycling of locally available resources. *Construction and Building Materials*, *285*, 122851.

Liew, Y. X., Doh, S. I., & Chin, S. C. (2023). A comprehensive review on the impact of micro and nano palm oil fuel ash in cementitious material. *Materials Today: Proceedings*.

Hamada, H. M., Al-Attar, A. A., Tayeh, B., & Yahaya, F. B. M. (2022). Optimizing the concrete strength of lightweight concrete containing nano palm oil fuel ash and palm oil clinker using response surface method. *Case Studies in Construction Materials*, *16*, e01061.

Hakeem, I. Y., Amin, M., Agwa, I. S., Abd-Elrahman, M. H., Ibrahim, O. M. O., & Samy, M. (2023). Ultra-high-performance concrete properties containing rice straw ash and nano eggshell powder. *Case Studies in Construction Materials*, *19*, e02291.

Hafez, R. D. A., Tayeh, B. A., & Abdelsamie, K. (2022). Manufacturing nano novel composites using sugarcane and eggshell as an alternative for producing nano green mortar. *Environmental Science and Pollution Research*, *29*(23), 34984-35000.