Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 5 Issue 2 (September 2026), 129-136
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v5i2.JSCET_S_000041

Development of a Sustainable Hydrophobic Concrete Surface Treatment using Palm Oil Mill Effluent (POME) and Calcium Carbonate

Nurjuhanah Juhari [1], Norlizan Wahid[1*], Muhammad Esma Haikal Mohd Norhisyam[1], Hazrina Ahmad[2]

[1] Center for Civil Engineering Studies, Universiti Teknologi MARA Cawangan Pulau Pinang, 13500 Permatang Pauh, Pulau Pinang, Malaysia
[2] Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

*Corresponding author: norlizanwahid@uitm.edu.my

Received: 23 June 2026 / Revised: 26 August 2026 / Accepted: 27 August 2026 / Published online: 30 September 2026

Abstract

Moisture penetration in concrete structures accelerates deterioration, necessitating effective surface protection to extend service life. At the same time, untreated raw palm oil mill effluent (POME) disposal poses severe environmental challenges due to high chemical and biological oxygen demands. This study investigates the development of a sustainable hydrophobic coating by repurposing raw POME and calcium carbonate ($CaCO_3$) to determine its optimal mixture ratio and evaluate its water absorption capacity on concrete. Coating solutions were synthesised using varying POME volumes (25 to 100 mL) and $CaCO_3$ amounts (1.0 to 3.0 g) in 50 mL of ethanol solvent, then applied to mortar cubes. Surface hydrophobicity and moisture resistance were evaluated via water contact angle (WCA) and 7- and 14-day water absorption tests. The treatment successfully lowered surface energy, rendering the mortar surfaces hydrophobic. A maximum WCA of 130.6° was achieved on the mortar surface using the highest tested concentration of 100 mL POME and 3.0 g $CaCO_3$. However, the optimum resistance to prolonged water absorption was recorded at an intermediate formulation of 75 mL POME and 2.0 g $CaCO_3$, yielding minimum absorption rates of 2.0% and 2.3% at 7 and 14 days, respectively. Higher material concentrations reduced moisture resistance, potentially due to excessive coating thickness and particle agglomeration that induced microcracking after drying. The use of low-cost POME as a coating constituent also offers potential material cost savings compared with conventional synthetic waterproofing agents, while improved moisture resistance may reduce long-term maintenance requirements. Overall, the developed coating provides a potentially cost-effective and environmentally sustainable approach to concrete protection while simultaneously valorising POME waste and mitigating associated aquatic pollution risks.

Keywords: Palm oil mill effluent (POME), Calcium carbonate ($CaCO_3$), Hydrophobic surface treatment, Water contact angle, Water absorption

---

1 Introduction

The durability of concrete is often compromised by moisture penetration that leads to material degradation and increasing maintenance costs. In countries with high humidity and frequent precipitation, such as Malaysia, continuous water infiltration can accelerate concrete deterioration mechanisms such as reinforcement corrosion and alkali-silica reactions. As a protective measure, hydrophobic surface treatment has become an effective

technique to delay deterioration. It creates a water-repellent barrier that reduces capillary water absorption while allowing internal vapour to escape (Habibnejad Korayem et al., 2020; Kavitha et al., 2023).

Recent studies have focused on sustainable organic and hybrid materials derived from silica-rich industrial waste, utilising the hydrophilic nature of silica to form stable protective barriers on concrete surfaces (Abdul Patah et al., 2020; Juhari et al., 2023; Saharudin et al., 2018; Wong et al., 2015). One such material is palm oil mill effluent (POME), an agricultural byproduct known to contain natural fatty acids and silica particles (A. Aziz & Hanafiah, 2017; Kareem et al., 2022). Malaysia, as a leading global producer of palm oil, faces an increasing burden of POME waste. Characterised as a thick brownish liquid with high concentrations of solids, oil and grease, as well as elevated chemical oxygen demand (COD) and biological oxygen demand (BOD) values (A. Aziz & Hanafiah, 2017; Chan & Chong, 2019; Kamyab et al., 2018), untreated POME poses significant environmental and aquatic threats if improperly discharged.

Using inexpensive, widely available POME as a chemically modified hydrophobic agent significantly lowers initial treatment costs compared to synthetic alternatives (Jahi et al., 2015). This practice aligns with sustainable construction by recycling industrial waste and reducing the overall environmental impact of concrete production (Kareem et al., 2022). Ultimately, enhancing concrete durability through these hydrophobic treatments minimises maintenance frequency, which results in significant long-term lifecycle cost savings (Sidhu & Kumar, 2023).

To enhance the adhesion and pore-sealing properties of surface coatings, hydrophobic agents are often formulated with solvents and mineral fillers (Szymańska et al., 2022). Ethanol acts as the solvent, while $CaCO_3$ nanoparticles enhance water repellence through increased surface roughness and matrix densification (Ma et al., 2021; Wang et al., 2024). However, the direct formulation of a hydrophobic surface treatment using raw POME, CaCO3, and an ethanol solvent remains largely unexplored. Addressing this specific gap provides a novel, eco-friendly waterproofing solution for concrete. This research aims to determine the optimum ratio of $CaCO_3$ and POME to achieve concrete hydrophobicity and to evaluate the water absorption capacity of mortar cubes coated with the developed POME and $CaCO_3$ surface treatment.

This research bridges industrial waste management and sustainable building practices by repurposing raw palm oil mill effluent (POME) as an organic hydrophobic agent. The approach offers dual benefits by reducing the environmental burden on mill operators and providing a sustainable alternative to commercial waterproofing agents for concrete surface treatment. The use of recycled resources supports the long-term development of green infrastructure by protecting concrete against rapid degradation while minimising environmental threats to the Malaysian water table.

2 Research Method

Fatty acids derived from palm oil mill effluent (POME) were the primary component of the hydrophobic solution samples used in this study. Raw POME was collected from the acidification pond of a palm oil industrial factory in Pulau Pinang, Malaysia. The organic liquid fraction containing fatty acids was separated using cloth filtering to remove coarse suspended particulates. Calcium carbonate ($CaCO_3$) powder and ethanol solution were used as the mineral functional filler and carrier solvent, respectively.

The hydrophobic coating solutions were formulated using various amounts of POME, a constant 50 mL volume of ethanol and different masses of calcium carbonate, as shown in Table 1. The procedure was initiated by homogenising the POME and ethanol in an ultrasonic cleaner for 30 minutes. Subsequently, the mixture was stirred for an hour at 350 rpm with a magnetic stirrer while calcium carbonate was gradually added.

Table 1. Experimental design matrix and material composition for hydrophobic solutions

Group solutions	POME (ml)	$CaCO_3$ (g)	Ethanol (ml)
POME 25ml	25	1.0, 1.5, 2.0, 2.5, 3.0	50
POME 50ml	50	1.0, 1.5, 2.0, 2.5, 3.0	50
POME 75ml	75	1.0, 1.5, 2.0, 2.5, 3.0	50
POME 100ml	100	1.0, 1.5, 2.0, 2.5, 3.0	50

To evaluate water repellence and water absorption capacity, standard mortar cubes measuring 50 × 50 × 50 mm were cast. The mortar surfaces were polished using sandpaper to create a smooth surface that enhances water-repellent performance. A primer layer of 3M Super 77 adhesive was then uniformly sprayed perpendicular to the surface from a maximum distance of 10 cm to improve interfacial adhesion. Finally, the synthesised hydrophobic solutions were sprayed onto the prepared mortar cubes. The coating process was also applied to glass slides as the control samples.

The effectiveness of a hydrophobic surface is primarily characterised by its water contact angle (WCA). Surfaces are categorised as hydrophilic if their WCA is below 90°, hydrophobic if between 90° and 150°, or superhydrophobic if greater than 150° (Mohamed, 2022). The WCA measurements were conducted on glass slides, followed by the mortar surfaces in accordance with ASTM D7334-08. Distilled water droplets (2–5 μL) were carefully deposited onto the coated glass slides and mortar surfaces using a pipette. Droplet profiles were captured using a digital microscope and analysed using ImageJ software equipped with a contact angle plugin.

The water absorption capacity of the mortar cubes was assessed in accordance with ASTM C1403. The specimens were oven-dried at 105 ± 5°C to remove internal moisture, then cooled before the initial dry weight (W_d) was recorded. The specimens were then sprayed with the hydrophobic coating at a distance of 10 cm on all surfaces. After drying, the specimens were fully immersed in water. Saturated weights (W_s) were recorded at intervals of 7 and 14 days, and the water absorption percentage was calculated using the equation (1).

$$\text{Water absorption (\%)} = (W_s - W_d)/W_d \times 100 \quad (1)$$

3 Results and Discussion

The test results plotted in Figure 1 show a positive correlation between the concentrations of POME and $CaCO_3$ and the resulting water contact angle (WCA). The formulations of the POME 25 mL group with various $CaCO_3$ contents did not achieve hydrophobicity. The treated mortar surfaces were categorised as hydrophilic, with WCA values ranging from 75.5° to 86.4° (< 90°). The treated mortar surfaces started to exhibit hydrophobic characteristics as the POME volume increased to 50 mL (POME 50 mL group) with WCA values surpassing the 90° threshold at $CaCO_3$ content of 1.5 g and higher. The treated mortar surfaces demonstrated significantly improved water repellence and consistent hydrophobicity in the POME 75 mL and POME 100mL groups across all $CaCO_3$ variations.

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 5 Issue 2 (September 2026), 129-136
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v5i2.JSCET_S_000041

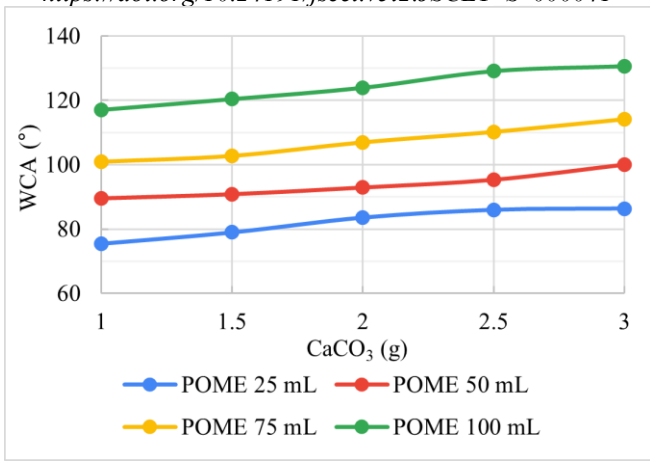
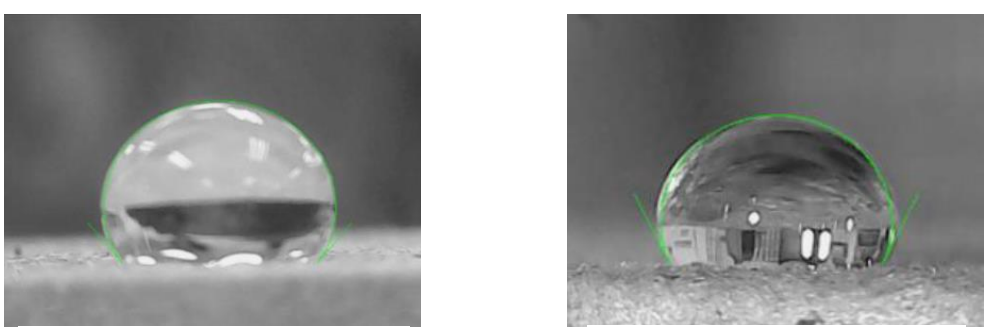


Figure 1. Water contact angle (WCA) as a function of $CaCO_3$ mass and POME volume.

The maximum WCA was observed in specimen POME 100 mL with 3g $CaCO_3$, which recorded a WCA of 133.3° on glass and 130.6° on the concrete surface. Figure 2 shows the photographic profiles of water droplets for the WCA measurement specimen POME 100 mL with 3g $CaCO_3$, showing a slight difference. Figure 3 shows the comparison of the WCA values of the POME 100 mL formulation on glass slide and mortar surfaces as a function of $CaCO_3$. The WCA measurements on the control glass slides were consistently higher than those recorded on the mortar surfaces across all variations.

The maximum WCA was observed for the POME 100 mL with 3g $CaCO_3$ formulation, which recorded a WCA of 133.3° on the glass slide and 130.6° on the mortar surface. Figure 2 presents photographic profiles of the water droplets for this specific specimen, showing a slight difference in WCA values. Figure 3 compares the WCA values of the POME 100 mL formulation on glass and mortar surfaces as a function of $CaCO_3$. The WCA measurements on the control glass slides were consistently higher than those recorded on the mortar surfaces across all variations.



a) WCA on glass slide

b) WCA on mortar surface

Figure 2. Photographic profiles of water droplets for WCA measurement on (a) a glass slide and (b) a treated mortar surface using the POME 100 mL with 3g $CaCO_3$ formulation

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 5 Issue 2 (September 2026), 129-136
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v5i2.JSCET_S_000041

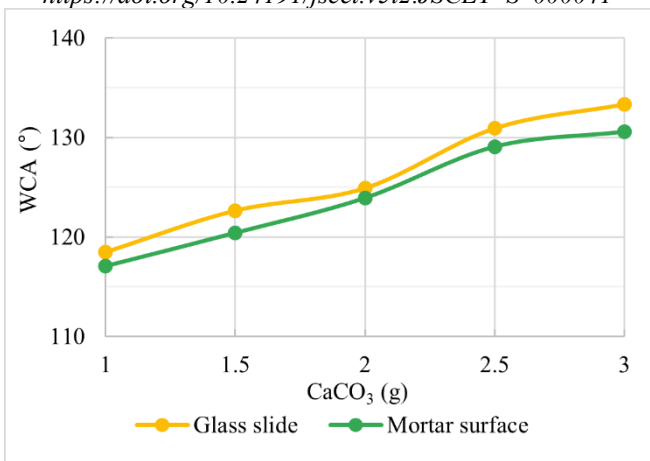


Figure 3. WCA values on glass slides and mortar surfaces across $CaCO_3$ variations for POME 100 mL

The water absorption results in Figure 4 at 7 and 14 days demonstrated a non-linear relationship with the formulation variables. Initially, as the POME volume increased from 25 mL to 75 mL, the water absorption progressively decreased. The most effective moisture resistance was achieved by the POME 75 mL group, which consistently recorded the lowest water absorption percentages. The optimum formulation was POME 75 mL with 2.0 g $CaCO_3$, which yielded the lowest overall absorption rates of 2.0 % at 7 days and 2.3% at 14 days. However, when the POME concentration was increased, as in the POME 100 mL group, the water absorption percentage experienced a slight rebound for both 7 and 14 days. Similarly, excessive additions of $CaCO_3$ beyond 2.0 g in the highly concentrated POME mixtures did not yield proportional improvements in absorption resistance.

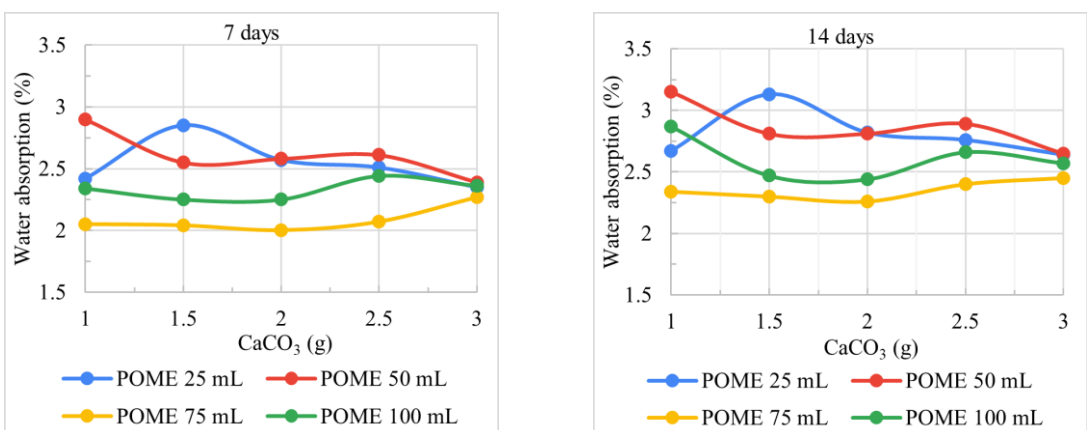


Figure 4. Water absorption (%) of treated mortar at 7 days and 14 days as a function of $CaCO_3$ content and POME volume

The findings confirm that the formulated organic surface treatment successfully achieved the research objectives by giving the mortar specimens hydrophobic characteristics and reducing their water absorption capacity. Natural fatty acids and silica particles contained in palm oil mill effluent (POME) act effectively to lower the surface energy of the concrete barrier (Kareem et al., 2022). The increase in WCA resulting from higher $CaCO_3$ content agrees with the findings from previous studies (Ma et al., 2021; Wang et al., 2024) that found $CaCO_3$ nanoparticles enhance water repellence by densifying the matrix and increasing surface roughness.

The high contact angle (130.56°) and low water absorption (2.26%) demonstrate the coating's strong hydrophobicity and potential to improve concrete durability. These findings support the literature, which highlights POME as an abundant, low-cost material that can simultaneously address industrial waste management challenges (Jahi et al., 2015). The use of POME also aligns with the environmental benefits of waste valorisation reported by Kareem et al. (2022). Furthermore, improved water resistance may reduce deterioration and maintenance requirements, contributing to lifecycle cost savings as discussed by Sidhu & Kumar (2023). Overall, the results are consistent with previous studies and support the potential of POME-based coatings for sustainable concrete protection.

A notable anomaly in the findings is the difference between the optimal formulations for maximum WCA and minimum water absorption. While the maximum WCA was reached at a formulation of 100 mL POME with 3.0 g $CaCO_3$, the optimal resistance to water absorption was achieved at intermediate concentrations of 75 mL POME with 2.0 g $CaCO_3$. This situation can be explained by the difference in the testing mechanisms. The WCA evaluates static surface tension against instantaneous moisture contact, while the 7- and 14-day absorption tests force water into the capillary pore network by applying constant hydrostatic pressure. Excessive amounts of POME (100 mL) or large dosages of $CaCO_3$ (3.0 g) are likely to result in an excessively thick coating or particle agglomeration on the mortar surface. Thus, this compromises the uniformity of the protective film, creating micro-cracks upon drying or failing to sufficiently penetrate and seal the internal capillary pores. As a result, water can pass through the barrier via micro-cracks during prolonged immersion, while a single droplet remains suspended on the aggregated rough surface. The POME 75 mL with 2.0 g $CaCO_3$ formulation represents the ideal mechanical balance, providing sufficient fatty acids and mineral fillers to generate optimal surface roughness without causing adverse agglomeration.

This study has significant implications for sustainable infrastructure development. Repurposing the raw POME can address the severe environmental burden faced by Malaysian mill operators, because untreated POME has high COD and BOD levels that could pose serious aquatic risks (A. Aziz & Hanafiah, 2017; Chan & Chong, 2019; Kamyab et al., 2018). This research successfully bridges the gap between waste management and civil engineering durability by transforming industrial waste into an efficient, environmentally friendly concrete surface treatment. The optimum formulation offers a feasible alternative to existing synthetic water proofers, which have the potential to reduce deterioration processes such as reinforcement corrosion and alkali-silica reactions in high-humidity climates (Habibnejad Korayem et al., 2020; Kavitha et al., 2023).

4 Conclusion

This study successfully demonstrated the feasibility of repurposing raw palm oil mill effluent (POME) and calcium carbonate ($CaCO_3$) to develop an organic hydrophobic surface treatment for concrete structures. The application of the formulated POME and $CaCO_3$ treatment effectively reduced the surface energy of the mortar specimens, transitioning them to a hydrophobic state. The surface hydrophobicity showed a positive correlation with constituent material concentrations. A maximum water contact angle (WCA) of 130.6° on the mortar surface was achieved with the application of the highest tested amount of 100 mL POME and 3.0 g $CaCO_3$.

However, the optimal formulation for resisting prolonged water absorption was found at the intermediate concentration of 75 mL POME combined with 2.0 g $CaCO_3$. This formulation yielded the lowest overall water absorption rates of 2.0% and 2.3% after 7 and 14 days of continuous immersion, respectively. The moisture resistance decreased with increasing POME volume to 100 mL or $CaCO_3$ quantity over 2.0 g. This behaviour is attributed to excessive coating thickness and particle agglomeration, which probably caused microcracking during drying and compromised the barrier's ability to completely seal internal capillary pores.

From an environmental and economic perspective, the study presents a dual-purpose solution by converting an abundant industrial waste stream into a functional concrete surface treatment. The use of POME as a readily available, low-cost material has the potential to reduce raw material costs compared with conventional synthetic waterproofing products while simultaneously providing a waste management strategy for mitigating the environmental impacts of untreated POME. Furthermore, improved moisture resistance may reduce concrete

deterioration and associated maintenance requirements, potentially contributing to lower lifecycle costs. These combined environmental and economic benefits support the potential application of POME and $CaCO_3$ as a more sustainable alternative to conventional concrete waterproofing treatments.

However, the findings are subject to limitations that must be addressed before commercial implementation. Water absorption was evaluated only over a 14-day period under controlled laboratory immersion conditions. The long-term durability and cost-effectiveness of the coating under environmental weathering, ultraviolet (UV) exposure, and abrasive conditions remain uncertain. Further studies involving accelerated weathering, long-term field exposure, formulation optimisation, and a detailed lifecycle cost analysis are therefore recommended to validate its long-term performance and economic viability.

Acknowledgments

The authors would like to acknowledge the support of Universiti Teknologi MARA Cawangan Pulau Pinang, Kampus Permatang Pauh, Pulau Pinang, Malaysia for providing the facilities on this research.

Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

Author Contribution

Nurjuhanah Juhari: Conceptualisation, methodology, investigation and writing - original draft; Norlizan Wahid: Conceptualisation, methodology, formal analysis, supervision, writing - review and editing; Muhammad Esma Haikal Mohd Norhisyam: Conceptualisation, formal analysis, investigation, methodology and validation; Hazrina Ahmad: Conceptualisation, writing - review and editing, and validation.

All authors have reviewed and approved the final version of the manuscript for publication.

Declaration of Generative Ai in The Writing Process

During the preparation of this work, the authors used Gemini Notebook in order to assist with structural drafting, improve language clarity, condense literature reviews, and format references according to journal guidelines. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Data Availability/Supplementary Materials

All data generated or analysed during this study are included in this published article.

Ethics Statement

The authors declare that this research did not involve human or animal subjects. All experimental procedures were performed following standard laboratory safety guidelines and institutional research protocols, complying with ASTM testing standards for material evaluation.

References

A. Aziz, N. I. H., & Hanafiah, M. M. (2017). The potential of palm oil mill effluent (POME) as a renewable energy source. *Acta Scientifica Malaysia, 1*(2), 09–11. https://doi.org/10.26480/asm.02.2017.09.11

Abdul Patah, M. F., Mohd Junaidi, M. U., Shum, K. M., Mohamad Nor, M. I., Danial Awalluddin, M. A., Abdul Nasir, N., & Hashim, A. (2020). Hydrophobic coating synthesized from palm oil based waste ash.

Materials International, 2(4), 458–464. https://doi.org/10.33263/materials24.458464

Chan, Y. J., & Chong, M. F. (2019). Palm oil mill effluent (POME) treatment: Current technologies, biogas capture and challenges. In D. C. Y. Foo & M. K. Tun Abdul Aziz (Eds.), *Green Technologies for the Oil Palm Industry* (pp. 71–92). Springer Singapore. https://doi.org/10.1007/978-981-13-2236-5

Habibnejad Korayem, A., Ghoddousi, P., Shirzadi Javid, A. A., Oraie, M. A., & Ashegh, H. (2020). Graphene oxide for surface treatment of concrete: A novel method to protect concrete. *Construction and Building Materials*, 243. https://doi.org/10.1016/j.conbuildmat.2020.118229

Jahi, N., Ling, S., Othaman, R., & Ramli, S. (2015). Modification of oil palm plantation wastes as oil adsorbent for palm oil mill effluent. *Malaysian Journal of Analytical Sciences*, 19, 31–40.

Juhari, N., Nurain Mustafa Kamal, S., Wahid, N., Ahmad, H., & Balqis Ismail, H. (2023). Effects of rice husk ash for water resilience material (hydrophobic coating). *In Solid State Science and Technology* (Vol. 31, Number 1).

Kamyab, H., Chelliapan, S., Din, M. F. M., Rezania, S., Khademi, T., & Kumar, A. (2018). Palm oil mill effluent as an environmental pollutant. In Palm Oil. *InTech.* https://doi.org/10.5772/intechopen.75811

Kareem, M. A., Orogbade, B. O., Ibiwoye, E. O., & Olasupo, N. O. (2022). The use of palm oil mill effluent as mixing and curing water in cement-based composite. *Silicon*, (14), 1285–1296. https://doi.org/10.1007/s12633-020-00864-w/Published

Kavitha, R., Ram Vivekananthan, M., Dhanagopal, K., Divyabharathi, P., Prabhakaran, M., & Ramprathap, M. (2023). An overview of water proofing system in concrete structures. *Materials Today: Proceedings.* https://doi.org/10.1016/j.matpr.2023.03.515

Ma, Y., Tian, P., Bounmyxay, M., Zeng, Y., & Wang, N. (2021). Calcium carbonate@silica composite with superhydrophobic properties. *Molecules, 26*(23). https://doi.org/10.3390/molecules26237180

Mohamed, D. (2022). Contact Angle Studies of Hydrophobic and Hydrophilic Surfaces. In Handbook of Magnetic *Hybrid Nanoalloys and their Nanocomposites* (pp. 761–782). Springer International Publishing. https://doi.org/10.1007/978-3-030-90948-2

Saharudin, K. A., Sreekantan, S., Basiron, N., Chun, L. K., Kumaravel, V., Abdullah, T. K., & Ahmad, Z. A. (2018). Improved super-hydrophobicity of eco-friendly coating from palm oil fuel ash (POFA) waste. *Surface and Coatings Technology*, 337, 126–135. https://doi.org/10.1016/j.surfcoat.2017.11.070

Sidhu, J., & Kumar, P. (2023). Comprehensive review on hydrophobic modification of concrete: Progress and perspectives. *Advances in Civil and Architectural Engineering, 14*(26), 155–180. https://doi.org/10.13167/2023.26.10

Szymańska, A., Dutkiewicz, M., Maciejewski, H., & Palacz, M. (2022). Simple and effective hydrophobic impregnation of concrete with functionalized polybutadienes. *Construction and Building Materials,* 315. https://doi.org/10.1016/j.conbuildmat.2021.125624

Wang, Y., Xiao, W., Wang, D., & Wang, J. (2024). Fluor-silane modified nano-calcium carbonate (CaCO3) as a hydrophobic coating for the conservation of sandstone via bio-inspired design. *Biogeotechnics, 2*(1). https://doi.org/10.1016/j.bgtech.2023.100064

Wong, H. S., Barakat, R., Alhilali, A., Saleh, M., & Cheeseman, C. R. (2015). Hydrophobic concrete using waste paper sludge ash. *Cement and Concrete Research*, 70, 9–20. https://doi.org/10.1016/j.cemconres.2015.01.005