



ORIGINAL RESEARCH ARTICLE

**MECHANICAL AND DURABILITY PERFORMANCE OF RICE HUSK ASH-PERIWINKLE SHELL ASH BLENDED CONCRETE UNDER CRUDE OIL EXPOSURE**  
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**ABSTRACT**

This study evaluates the mechanical and durability of grade 25 concrete modified with Rice Husk Ash (RHA) and Periwinkle Shell Ash (PSA) under crude oil exposure. RHA and PSA were incorporated at 0–10% replacement of cement by weight, while maintaining a constant water-to-cement ratio of 0.55. Concrete specimens were subjected to two curing regimes: 28 days of pre-curing in water and then followed by 62 days post-curing in crude oil immersion (totaling 90 days), and continuous crude oil immersion for 90 days. Mechanical and Durability were assessed through compressive strength and moisture absorption tests at 90 days of curing in line with BS standards. Microstructural investigations using Scanning Electron Microscopy (SEM) were carried out to examine pore refinement, crack morphology, and hydration products. The results indicate that optimal blends of ≈5–6% RHA and 4–5% PSA produced the best performance. They achieved higher density (e.g. C7=2730kg/mm<sup>3</sup> and W7=2803 kg/mm<sup>3</sup>), lower moisture absorption (e.g. W7=0.1785% and C6=0.486%), and improved retention of mechanical strength (e.g. W7=20.5N/mm<sup>2</sup> and C9=16.0N/mm<sup>2</sup>) compared to control samples. Water-cured specimens consistently outperformed those in crude oil by 7.87% in strength, yet RHA–PSA concretes exhibited slower strength loss and reduced microcracking under crude oil exposure. SEM images confirmed denser C–S–H gel networks and refined pore structures at optimal dosages, whereas higher ash contents increased porosity and susceptibility to deterioration. The findings demonstrate that moderate incorporation of RHA and PSA enhances both the mechanical and durability of concrete in crude oil environments (C7=15.0N/mm<sup>2</sup>), making these materials promising sustainable additives for infrastructure exposed to petroleum-polluted conditions.

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**1.0 Introduction**

Concrete is the most extensively used construction material worldwide owing to its versatility, ease of production, cost-effectiveness, and adaptability in diverse structural applications. Its performance is primarily associated with high compressive strength and durability; however, these qualities are significantly challenged in aggressive environments. In regions contaminated by crude oil, concrete is exposed to complex chemical interactions that degrade its microstructure, resulting in reduced strength and shortened service life. Several studies have shown that crude oil infiltration adversely affects concrete properties such as compressive and flexural strength, slump, permeability, shrinkage, and resistance to fire and chloride ingress (Osinubi et al., 2021; Ejuh & Uche, 2009; Ajagbe et al., 2013). Such deterioration threatens structural safety, increases maintenance costs, and undermines long-term sustainability.

To mitigate these effects, research attention has shifted toward the incorporation of Supplementary Cementitious Materials (SCMs), which improve strength development, densify the microstructure, and enhance resistance to chemical attack. Among locally available SCMs, Rice Husk Ash (RHA) and Periwinkle

Shell Ash (PSA) are of particular interest. RHA, rich in amorphous silica, contributes to additional calcium silicate hydrate (C–S–H) formation, thereby refining pore structure and improving impermeability (Holland, 2005; Holland, 2005; Ahmad et al., 2020). PSA, obtained from calcined periwinkle shells, is calcium-rich and chemically similar to Portland cement, offering pozzolanic reactivity while promoting sustainable waste utilization (Offiong & Akpan, 2017; Ezeokonkwo & Nwankwo, 2022).

Existing studies have examined RHA and PSA separately as cement replacements, but their combined performance under crude oil attack is not well documented. Given the abundance of both materials in oil-producing regions and frequent deterioration of concrete infrastructure due to crude oil exposure, there is a need to assess whether the pozzolanic synergy between RHA and PSA can enhance concrete durability in such environments. (Umasabor & Osinubi, 2021). This research gap is critical in oil-producing regions such as the Niger Delta, where crude oil spills are frequent and where both rice husks and periwinkle shells are abundant wastes that pose environmental challenges if left unutilized (Aimikhe & Lekia, 2022).

This study, therefore, investigates the durability of RHA–PSA blended concretes exposed to crude oil environments, with durability assessed through mechanical properties, moisture absorption, and density, complemented by micro-structural characterization via Scanning Electron Microscopy (SEM). The aim is to determine whether moderate RHA–PSA incorporation can improve the resilience of concrete against crude oil-induced degradation, while simultaneously promoting sustainable construction practices.

## 2. Materials and Method

### 2.1 Materials

The following materials were used for this research: Cement, aggregates, Periwinkle shell ash (PSA), Rice Husk Ash (RHA), water and crude oil. The cement used in this research is the Ordinary Portland Cement manufactured by Bua, Sokoto. The Cement was obtained from local dealers in Rijiyar Zaki in Kano. Aggregates were sieved in accordance with the specification of (BS EN 933-1:2012). Fine aggregate was found to be in zone II and the coarse aggregate (crushed granite) has nominal size of 20mm. Both the fine and coarse aggregates were sourced from Challawa River and Rimi Gado quarry respectively, in Kano. Rice Husk were obtained from local farmers at Konor Dawaki market in Kano and the dried Husks were calcined into ash at National Orthopedic Hospital Dala, Kano State at a calcination temperature of 700°C for two hours. Particles were sieved to a particle size of 150 µm. The Particle size (150 µm) ensures a rapid balance in reactivity and workability (as finer particles can increase water demand). (Akinwumi & Aidom, 2015; Olutoge & Amusan, 2014). Periwinkle shells were purchase at the beach market in Calabar and is of non-specific species. After the shells were washed thoroughly and dried, they were taken to Civil Engineering Material Laboratory of University of Uyo for calcination into ash. It was calcined at a temperature of 900°C as justified by Tayeh et al., (2019), Inyang & Etuk (2016), Offiong and Akpan (2017). Sieved for one hour to a Sieve size of 75 µm. Particle size of 75 µm was necessary to create difference in particle size from that of Rice Husk Ash, as to optimize their combined performance as admixtures in concrete. (Akinwumi & Aidom 2015; Olutoge & Amusan, 2014). The water for mixing and curing of the cubes was potable with PH value of 7, obtained from Civil Engineering Laboratory, Bayero University, Kano and met ASTM C1602/C1602M-18 specification. Crude Oil obtained from local miners in Ogoni land of Rivers State was of Qua Iboe type. No test was conducted to determine the precise composition. However, comparison is made with existing literature data where it is necessary.

### 2.2 Methods

#### 2.2.1 Concrete mix design

Grade 25 mix design was considered in accordance with DoE (1988) Mix Design method also known as Teychem et al. (1988) for normal Concrete mixes. Details of the quantities from the design of the control mix is presented in Table 1.

#### 2.2.2 Concrete mix

Ten mixes featuring varying RHA–PSA ratios were cast at a constant water- to-cement ratio of 0.55, with a combined optimal replacement content of 10% (Table 2). Varying ratios were necessary as to investigate their individual (eg. C1–C5) and combined effects (eg. C6–C10) on concrete properties and capping both

RHA and PSA at 10%, being that 10% is a common replacement level for supplementary materials. At this level (10%), we can balance both benefits and potential drawbacks, ensure optimal balance between performance, sustainability, and cost-effectiveness.

**Table 1:** Required material quantities

Materials	Quantity per cubic kg/m <sup>3</sup>
Cement	346
Water	190
Fine aggregate	663
Coarse	1232

**Table 2:** Percentage replacement of cement with RHA and PSA in crude oil, water/crude oil (adapted from STAT-EASE, 2023)

IDENTIFICATION MARK	RHA (%)	PSA (%)
C1/W1	0	0
C2/W2	6	0
C3/W3	10	0
C4/W4	0	6
C5/W5	0	10
C6/W6	5.25	4.75
C7/W7	6	4
C8/W8	5.5	4.5
C9/W9	5.75	4.25
C10/W10	5	5

### 2.2.3 Particle size distribution of aggregates

Samples (1000g each) of aggregates were mechanically agitated for five minutes, and the retained mass on each sieve was recorded to compute cumulative passing percentages in accordance with (BS EN 933-1:2012)

### 2.2.4 Specific gravity

The specific gravity of RHA, PSA, Fine, and Coarse aggregates was determined in accordance with ASTM C127 – 15) for coarse aggregates and ASTM C128-2022 for fine aggregates.

### 2.2.5 Compressive strength test

Concrete cubes (100 × 100 × 100 mm) were cured in various media and tested at 90 days using a YES-2000 digital compression testing machine (Jinan YES Testing Technology Co., Ltd., China) with a maximum Load capacity of 2000kN) in accordance with BS EN 12390-3: 2009. Samples cubes each were cured in water/crude oil and crude oil only by total immersion. There were cured in cured oil by total immersion as to avoid stratification, being that crude oil is immiscible with water. This stratification can lead to inconsistent strength test results (Salih et al., 2019; Ejah & Uche, 2009)

### 2.2.6 Density of cubes

Density of solid samples were determined after 48 hours (under laboratory conditions) post-curing in Crude and water/crude oil in accordance with BS 1881-114:1983. Drying was extended to 48h because proper drying could not be achieved at 24 hours.

### 2.2.7 Moisture absorptions test of cubes

Determined after curing 90 days in crude Oil, and in water/crude oil media in accordance with BS EN 1881-122:2011.

### 2.2.8 Microstructural properties of rice husk ash admixed with periwinkle shell ash

Microstructural properties of RHA and PSA is carried out using a Phenom ProX Scanning Electron Microscope (Phenom-World B.V., Eindhoven, Netherlands). The Aim is to determine the morphology of the

samples. The test was conducted at Chemical Engineering Department of Ahmadu Bello University, Zaria. The following samples were used for the SEM analysis: C1 (representing 0% RHA+0% PSA dosage), C2 (representing 6%RHA & 10%RHA dosage), C5 (representing 6% PSA & 10% PSA dosage), and C9 (optimal blend, ≈5–6% RHA & 4–5%PSA) all cured in crude oil for 90 days.

### 3. Results and Discussion

This section presents the results and discussion on the physical, mechanical and durability properties of tests carried out. It also presents and discusses the microstructural analysis of RHA-PSA concrete.

#### 3.1. Physical Properties

##### 3.1.1 Properties of aggregates

The particle size distribution of the aggregates used met the international standard (BS EN 206-2013) for structural concrete production. The coarse aggregates (Figure 1) were dominated by a nominal maximum size of 20 mm, complying with (BS EN 206-2013) specifications for workability and flowability (Khaleed et al., 2011). The fine aggregates (Figure 2) fell within Zone II of (BS 882-1992), with particle sizes ranging from 63 μm to 2 mm. The 600 μm sieve retained the highest proportion (26.1–26.3%). This grading ensures adequate packing density and satisfactory workability (Kulkarni et al., 2009).

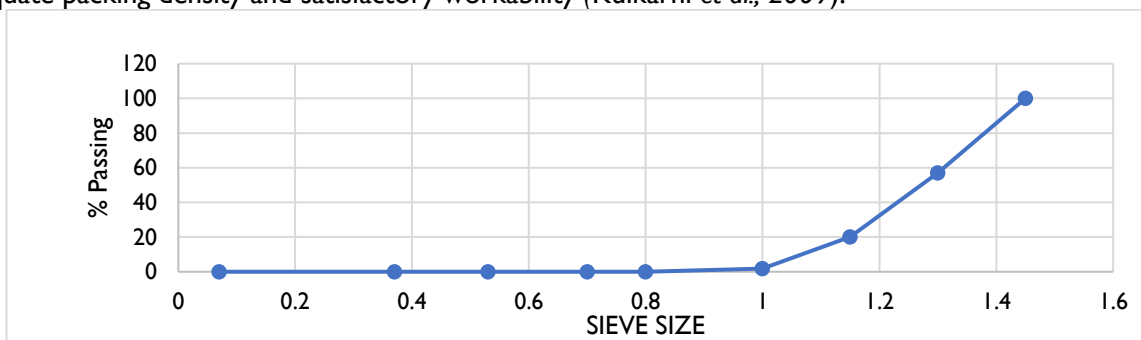


Figure 1: Particle size distribution of coarse aggregates

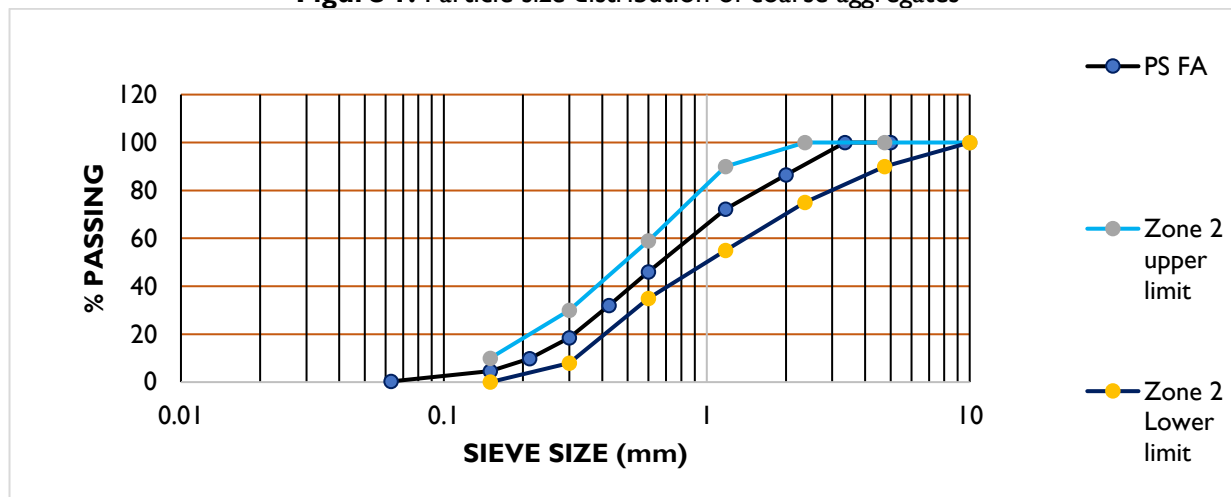


Figure 2: Particle size distribution of fine aggregates

##### 3.1.2 Specific gravity of aggregates

The specific gravities of the constituent materials were found to be 2.71 for coarse aggregate, 2.58 for fine aggregate, 2.49 for PSA, and 1.79 for RHA. These values fall within acceptable ranges of 2.50 and 2.90 for normal-weight aggregates (ASTM C127/128-15/22). The relatively lower specific gravity of RHA is attributed to its porous structure and calcination temperature, which decreases bulk density at higher firing temperatures (Taku et al., 2016). The PSA value aligns with reported values by (Olusola & Umoh, 2012), confirming its suitability as a cementitious additive.

Table 6: Specific gravity of materials

Material	PSA	RHA	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.49	1.79	2.58	2.71

### 3.1.3 Slump test results

Slump test results as presented in Figure 3, indicate variable workability across mixes. The blend with 5.25% RHA + 4.75% PSA (C6/W6) recorded a slump of 42 mm, within the design range of 30–60 mm, indicating good workability. The control mix (0% RHA, 0% PSA) exhibited a slump of 33 mm, while the 10% PSA mix (B5/W5) recorded 31 mm. In contrast, the 10% RHA (C3/W3) exhibited zero slump, producing a harsh and unworkable mix due to the high-water demand of RHA, caused by its porous structure and large surface area. Similar observations have been reported by (Zhang et al., 2018; Habeeb & Bin Mahmud, 2010). The use of superplasticizers has therefore been recommended to improve flowability and cohesiveness in RHA-rich mixes (Kamau et al, 2017).

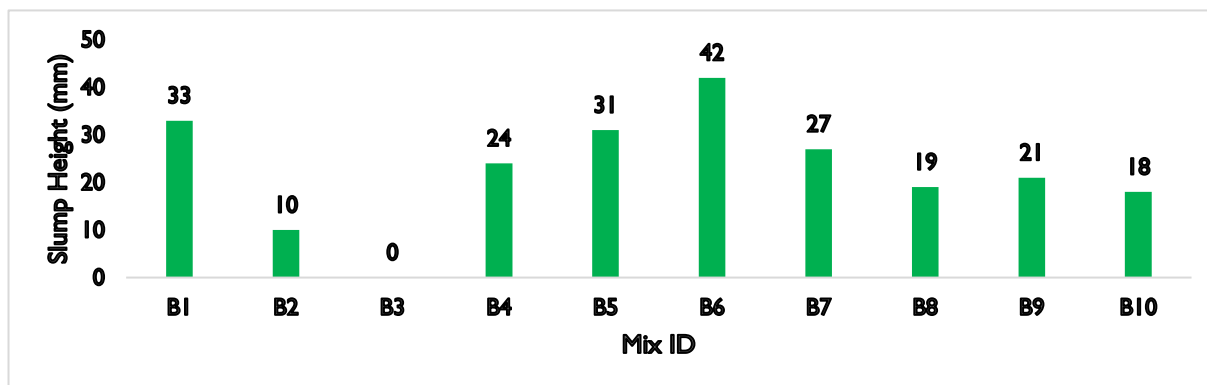


Figure 3: Workability test

### 3.1.4 Density of Cubes in Crude Oil and in Water/Crude Oil

Figure 4 presents the density variations of cubes subjected to different curing regimes. Among the cubes, water/crude oil-cured specimens exhibited superior performance, with W7 recording the highest density (2803 kg/m<sup>3</sup>) compared to the control (2445 kg/m<sup>3</sup>). In contrast, C7 (2730 kg/m<sup>3</sup>) recorded the highest density among crude oil-only cured cubes. This demonstrates that initial water curing enhances hydration and matrix densification, consistent with the observations of (Mehta & Monteiro, 2014) and (Neville, 2011), who emphasized the critical role of early curing in reducing porosity and improving long-term durability. Similarly, (Zhang et al., 2018) reported that preconditioning concrete in water provides

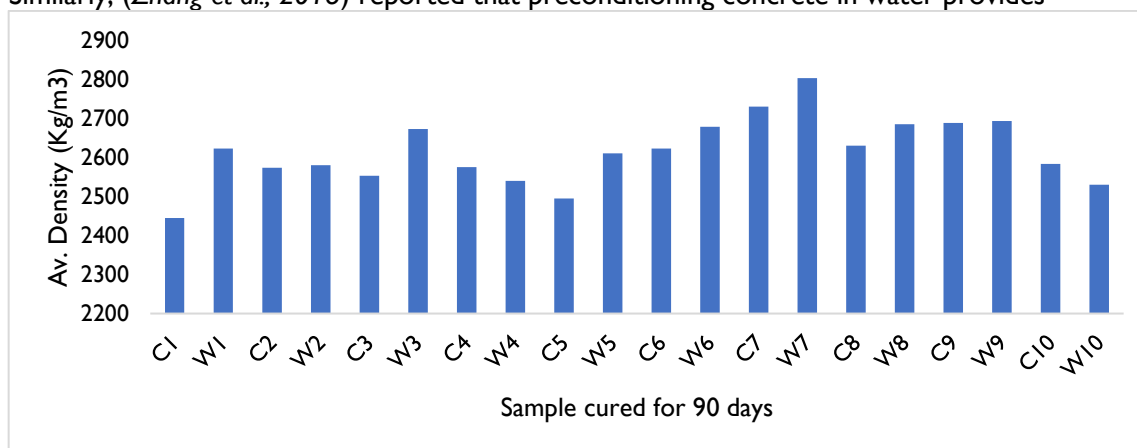


Figure 4: Average density of concrete mixes in Crude Oil and in water/crude oil for 90 days

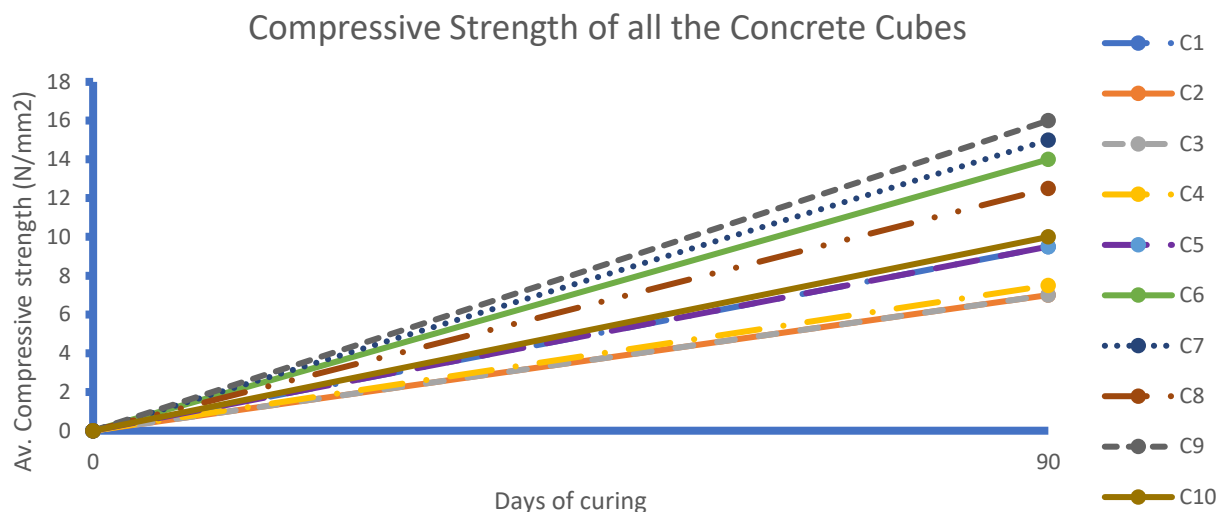
adequate internal moisture for cement hydration before exposure to aggressive media such as crude oil.

## 3.2. Mechanical Property Test

### 3.2.1. Compressive Strength Tests for Cubes Cured in Crude Oil

The compressive strength results after 90 days of curing in crude oil varied significantly across the mixes, ranging from 7.0 N/mm<sup>2</sup> to 16.0 N/mm<sup>2</sup>. The lowest strengths were observed in C2, C3, and C4 (7.0–7.5 N/mm<sup>2</sup>) being that mix is either rich in Silica from RHA or Calcium oxide from PSA only, while the highest was recorded in C9 (16.0 N/mm<sup>2</sup>), a combined effect of silica in RHA and calcium oxide in PSA (Figures 5).

The control specimen, C1, reached only 9.5 N/mm<sup>2</sup>, confirming the adverse effect of crude oil immersion on the concrete performance. This outcome supports the fact that crude oil infiltration disrupts hydration processes by forming a hydrocarbon film on cement grains, which impedes water ingress, reduces hydration, and weakens the cementitious matrix (Ejeh & Uche, 2009; Ajagbe et al. 2013; Osinubi et al., 2021).



**Figure 5:** Compressive strength of Concrete cubes cured in Crude oil for 90 Days

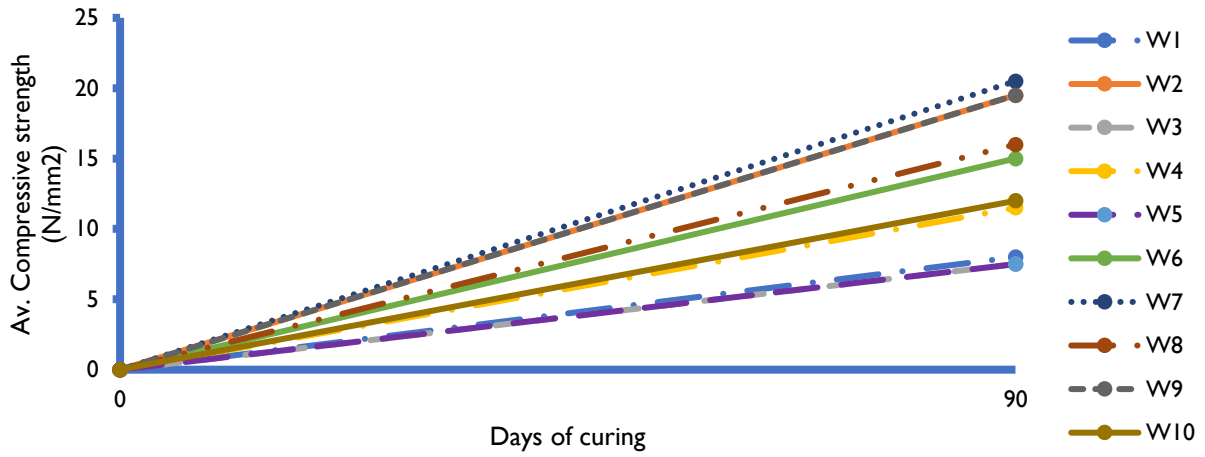
Despite the generally detrimental effect of crude oil curing, mixes with moderate RHA–PSA incorporation (C6–C9) demonstrated markedly better performance. For instance, C9 (16.0 N/mm<sup>2</sup>) outperformed the control (C1) and other high-ash mixes, highlighting the synergistic effect of silica-rich RHA and calcium-rich PSA. The pozzolanic reaction of amorphous silica in RHA with calcium hydroxide forms additional calcium silicate hydrate (C–S–H), while PSA contributes calcium oxide, which enhances the formation of both C–S–H and calcium aluminate hydrates (C–A–H) which limits oil penetration, reduces hydrocarbon formation around particles thus, minimizing oil’s negative impacts on cement hydration and strength. This dual mechanism reduces the hydrocarbon film formed around the particles, refines the pore structure, reduces permeability, and strengthens the interfacial transition zone (Holland, 2005; Holland, 2005; Chindaprasirt et al., 2007). These effects are consistent with reports that SCMs improve concrete resistance to chemical attack by densifying the matrix and limiting ingress of aggressive agents (Thomas, 2007; ACI Committee 232. 2014).

Overall, the results suggest that moderate incorporation of RHA (≈5–6%) and PSA (≈4–5%) provides the optimum balance between hydration, pozzolanic activity, adverse chemical effect from crude and provides filler effects. These mixes (C6–C9) not only outperformed the control in compressive strength but also demonstrated slower degradation under crude oil exposure.

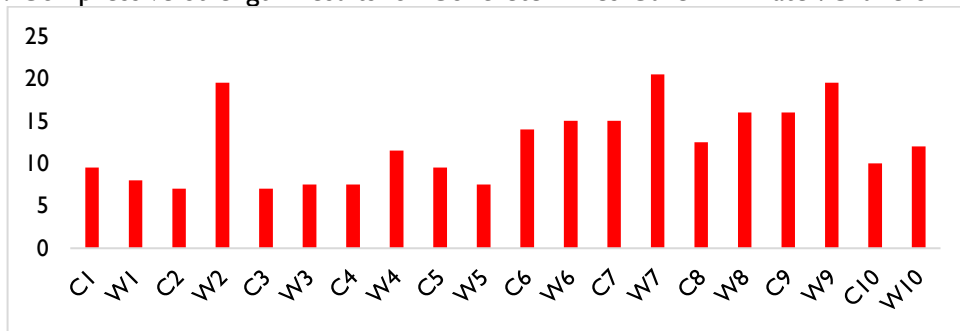
### 3.2.2. Compressive Strength Test for cubes cured in Water/Crude Oil

Figure 6 illustrates the compressive strength performance of cubes cured in water for 28 days and subsequently in crude oil for 62 days, giving a total curing day of 90. Among all mixes, W7 achieved the highest compressive strength of 20.5 N/mm<sup>2</sup>, significantly surpassing the control mix (8.0 N/mm<sup>2</sup>) by 156.25%. This superior performance can be attributed to the initial water curing, which promoted early hydration of cement and the formation of a denser calcium silicate hydrate (C–S–H) microstructure, thereby enhancing resistance to crude oil attack (Mehta & Monteiro, 2014).

In Figure 7, the comparative results between water–crude oil-cured and crude oil-only cured specimens highlight a clear trend: concretes subjected to an initial water-curing phase consistently developed higher strengths. This finding aligns with previous research, which emphasizes that initial water curing facilitates more complete hydration, reducing porosity and improving resistance before exposure to aggressive media such as crude oil (Zhang et al., 2018). Consequently, the study demonstrates that pre-conditioning concrete in water substantially improves its long-term durability under crude oil exposure.



**Figure 6:** Compressive Strength Results for Concrete Mixes Cured in Water/Crude oil for 90 Days

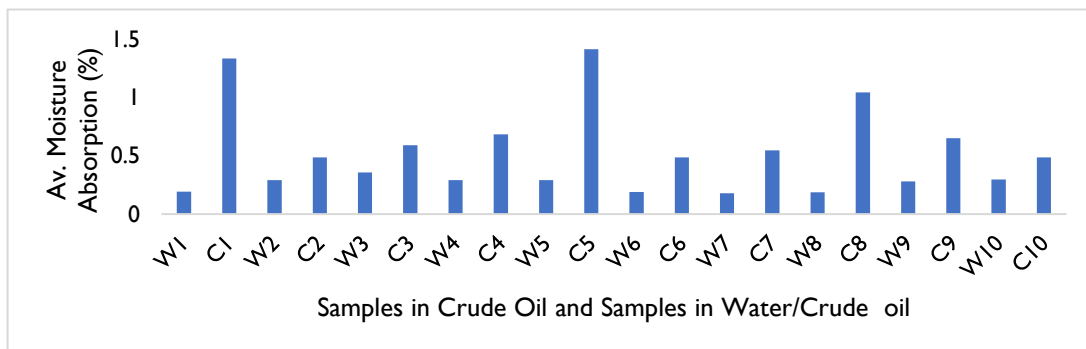


**Figure 7:** Average compressive strengths of concrete mixes cured in water/Crude Oil and crude oil for 90 days

### 3.3 Durability Test

#### 3.3.1. Moisture Absorption of Concrete mixes

Figures 8 illustrates the moisture absorption behavior of concrete cubes exposed to different curing environments. The results indicate that crude oil-cured cubes exhibited significantly higher moisture absorption (C5: 1.412%) compared to water/crude oil-cured cubes (W5: 0.2905%). This observation can be attributed to the penetration of hydrocarbons from crude oil, which disrupts the cement matrix and increases capillary continuity and permeability (Al-Amoudi, 2015).



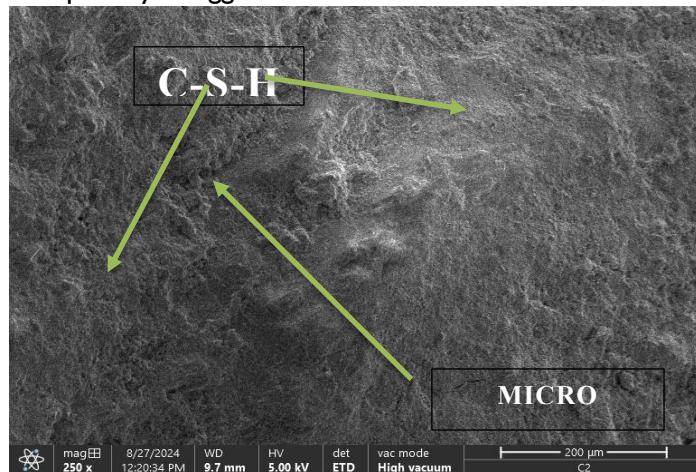
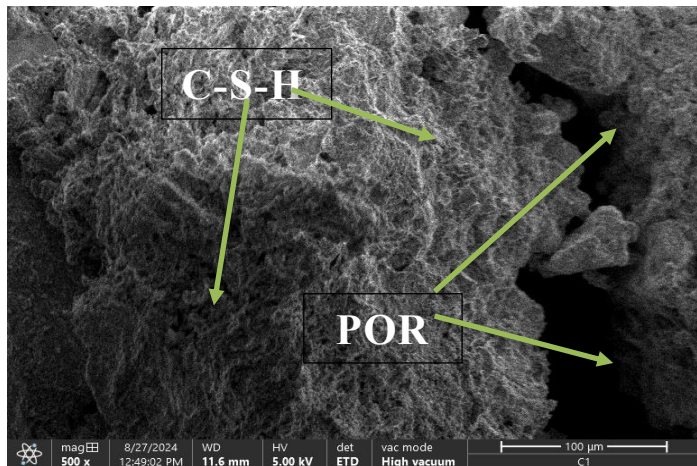
**Figure 8:** Average moisture absorption of concrete mixes containing RHA and PSA cured in water/crude oil and continuously in crude oil for 90 days.

The elevated absorption observed in crude oil-cured samples is primarily linked to chemical deterioration of the cementitious matrix. Hydrocarbon interaction leads to leaching of calcium hydroxide and partial decalcification of hydration products, thereby enlarging the capillary pores and reducing matrix cohesion (Mehta & Monteiro, 2014). In contrast, specimens incorporating Rice Husk Ash (RHA) and Periwinkle Shell Ash (PSA) showed significantly lower moisture absorption. The pozzolanic reactivity of these materials produces additional calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H), filling internal voids and improving microstructural density (Olutoge, 2020). This densification effect results in lower

permeability and enhanced durability, confirming the potential of RHA–PSA blended systems in mitigating crude oil–induced deterioration. In summary, C6 (0.486%) and W7(0.1785%) recorded the least absorption rate for samples cured entirely in crude oil and water/crude oil respectively.

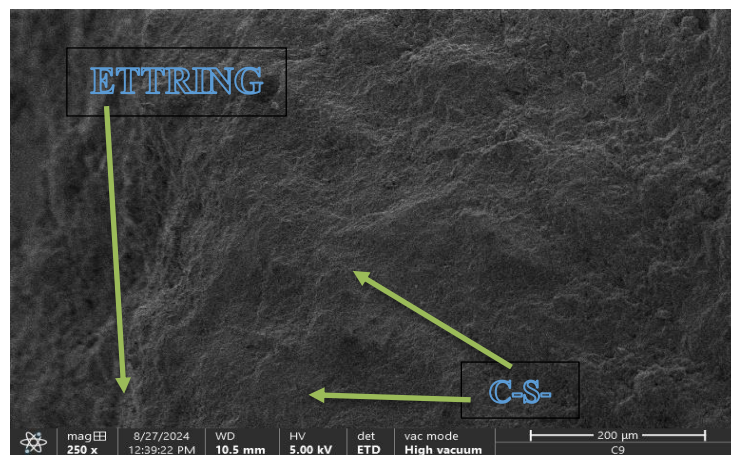
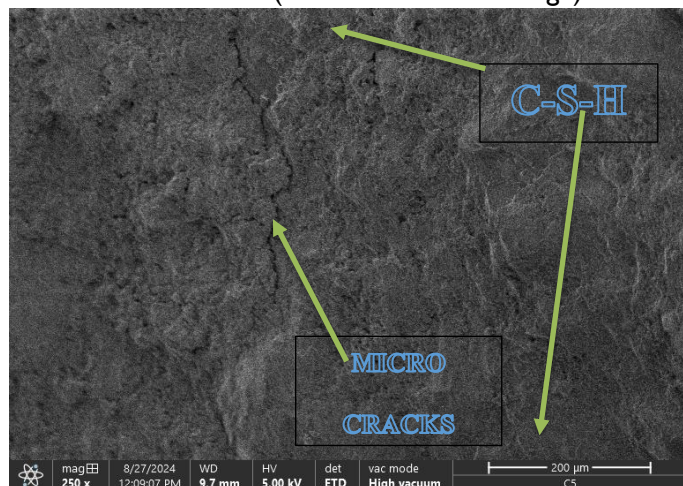
### 3.3.2 Microstructural analysis

The SEM micrograph (500x) of the control specimen (Plate 1-C1) illustrates a porous and discontinuous microstructure with poorly developed hydration products. Large voids and weakly bonded C–S–H gel dominate the matrix, indicating high permeability and susceptibility to aggressive crude oil attack.



**Plate 1:** C1(0% RHA-0% PSA dosage)

**Plate 2:** C2(6%RHA & 10%RHA dosage)



**Plate 3:** C5(6% PSA & 10% PSA dosage) **Plate 4:** C9(optimal blend, ≈5–6% RHA & 4–5%PSA)

This morphology directly explains the relatively low compressive strength recorded ( $\approx 9.5 \text{ N/mm}^2$ ) and highlights the vulnerability of plain OPC concrete to hydrocarbon contamination. For the C2 (Plate 2) specimen (6%RHA & 10%RHA dosage), the micrograph (250x) shows scattered C–S–H gels alongside widespread microcracks. These cracks likely developed due to incomplete hydration and the disruptive effects of crude oil infiltration, which restricts water penetration and coats cement grains, slowing pozzolanic reactions. The poor structural connectivity of the hydration products corresponds with the very low compressive strength ( $\approx 7 \text{ N/mm}^2$ ), confirming that suboptimal replacement levels of RHA and PSA do not provide adequate refinement of pore structure.

The C5 (Plate 3) micrograph (250x) (6% PSA & 10% PSA dosage) reveals slightly improved C–S–H gel formation compared to C2, but still displays visible microcracks and significant porosity. This suggests partial improvement from SCM incorporation but insufficient balance between RHA and PSA to optimize hydration and pore refinement. The result is only moderate strength gain ( $\approx 9.5\text{--}10 \text{ n/mm}^2$ ) compared to the control, underscoring the adverse effect of imbalanced replacement levels that either increase water demand (RHA) or reduce available clinker (PSA).

In contrast, the C9 (Plate 4) micrograph (250x) (optimal blend, ≈5–6% RHA and 4–5% PSA) presents the densest and most refined microstructure. The SEM shows compact C–S–H gel, limited microcracks, and traces of ettringite, all of which indicate active hydration and a well-developed cementitious matrix. The denser microstructure results from the synergistic pozzolanic reactions: RHA provides silica for secondary C–S–H, while PSA supplies calcium that sustains hydration. This explains the superior compressive strength of 16.0 N/mm<sup>2</sup> and improved durability performance recorded for this mix.

#### 4. Conclusion

1. Strength reduced below 25 N/mm<sup>2</sup> for all samples exposed to crude oil; however, C9 (cubes) showed better durability. Water pre-curing enhanced crude oil resistance.
2. Water-Crude oil cured specimens consistently performed better than crude oil immersion samples, yet RHA–PSA concretes exhibited slower degradation and improved resistance under crude oil immersion.
3. Mechanical and durability tests revealed that optimal blends of approximately 5–6% RHA and 4–5% PSA achieved higher compressive strengths, reduced moisture absorption, and greater density compared to the control and non-optimal mixes.
4. SEM analysis supported these findings by showing that the control and high-ash mixes developed porous, microcracked structures, whereas the optimal blends exhibited dense C–S–H gel networks, refined pore structures, and limited microcracking. These microstructural improvements confirm the role of RHA–PSA synergy in enhancing impermeability and mitigating crude oil-induced deterioration.
5. The study demonstrates that the mechanical and durability properties of concrete exposed to crude oil environment can be significantly enhanced through moderate incorporation of RHA and PSA, which has improved on the long-term durability and microstructural integrity of concrete, offering a sustainable and effective strategy for infrastructure in petroleum-polluted regions.

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