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Structural And Durability Properties of Palm Kernel Shell Concrete

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ABSTRACT

This study aims to evaluate the suitability of Palm Kernel Shell (PKS) concrete for structural applications and durability. The study characterize the physical and chemical properties of PKS to determine its suitability as a construction material. Various mix proportions were prepared by partially replacing coarse aggregates with PKS (i.e., 20%, 30%, and 40%). The fresh and hardened properties of the PKS concrete were evaluated. These include workability, compressive strength, and flexural strength. Furthermore, the durability properties of PKS concrete were assessed through tests evaluating its resistance to water absorption, and acid attack. The study found that normal concrete had the highest compressive strength across all curing periods, while PKS concrete showed a decrease in strength as the PKS content increased, with 40% PKS exhibiting the lowest values. The density of PKS concrete decreased with higher PKS content, making it lighter than normal concrete. Tensile strength also decreased with increasing PKS content, with normal concrete outperforming PKS concrete. PKS concrete absorbed more water than normal concrete, indicating higher porosity, and was less resistant to acid attack compared to normal concrete. PKS concrete is a lightweight and eco-friendly material but has lower mechanical strength, higher water absorption, and reduced acid resistance compared to normal concrete, necessitating further research to optimize its properties for structural use.

Keywords: *structural application, durability properties, normal concrete, compressive strength, acid attack.*

I. INTRODUCTION

Concrete is the most widely used man-made material in construction globally. However, its high production costs, primarily due to the expense of cement and aggregates, have created a pressing need for alternative materials. Despite the rising demand for concrete, the construction industry faces increasing pressure to adopt sustainable practices and minimize environmental impacts (Wang et al., 2020). One promising solution is the use of waste materials, such as palm kernel shells (PKS), as alternative aggregates in concrete production (Kumar et al., 2020). PKS, a byproduct of the palm oil industry, is abundant in tropical regions and offers a readily available solution (Anwar et al., 2019). Incorporating PKS into concrete can reduce reliance on natural aggregates, conserve resources, and lower carbon footprints (Baredar et al., 2020).

The construction industry currently produces approximately 25 billion tons of concrete annually, with projections indicating a 12-23% increase in global cement production by 2050 (WBCSD, 2007). This overwhelming demand for concrete has led to significant depletion of naturally occurring aggregates, causing irreparable environmental damage. Consequently, the search for more sustainable and renewable materials has intensified. Agricultural waste materials, such as sawdust, maize cobs, rice husks, coconut shells, and palm kernel shells, can serve as effective substitutes for traditional construction materials.

Lightweight concrete offers numerous advantages, including enhanced fire resistance, thermal insulation, sound absorption, and frost resistance (CEB/FIP, 1977). The production of lightweight aggregates (LWA) can be achieved through various methods (Polat et al., 2010). PKS, also known as oil palm shells (OPS), has been researched as a lightweight aggregate since 1985 (Salam and Abdullah, 1985). The oil palm industry is significant in countries like Malaysia, Indonesia, and Nigeria, where PKS can be utilized to produce structural lightweight aggregate concrete (Teo et al., 2007; Abdullah, 1996). Utilizing this agricultural waste not only reduces construction material costs but also addresses waste disposal issues.

Despite its potential benefits, the structural and durability properties of PKS concrete remain poorly understood (Kumar et al., 2020). Research is needed to investigate its mechanical properties, durability, and performance under various environmental conditions (Wang et al., 2020). This study aims to address the knowledge gap and explore the structural and durability properties of PKS concrete, contributing to the development of eco-friendly construction materials and practices.

A. *Statement of the Problems*

The adoption of palm kernel shells as a sustainable alternative to traditional aggregates in concrete production is hindered by a limited understanding of their structural and durability properties. The performance of PKS concrete under various environmental conditions and its long-term durability are not well understood, complicating its use in construction projects. The rising cost of construction materials, such as granite and gravel, necessitates the search for cheaper yet durable substitutes. Unused palm kernel shells often become environmental pollutants, contributing to greenhouse gas emissions. Previous studies have explored the use of PKS in concrete, but comprehensive investigations into its structural and durability properties are lacking.

B. *Aim and Objectives of the Study*

The aim of this study is to investigate the structural and durability properties of palm kernel shell concrete. The following objectives were established:

1) To evaluate the compressive strength of palm kernel shell concrete concerning required standards for structural applications.
2) To investigate the durability of palm kernel shell concrete, focusing on its permeability and resistance to chemical attacks.
3) To determine the workability of concrete made with palm kernel shells compared to normal weight aggregates.

C. *Research Scope*

The research scope involves investigating the structural and durability properties of palm kernel shell concrete, aiming to provide insights into its potential as a sustainable construction material. Key parameters include compressive strength, splitting tensile strength, water absorption, and permeability characteristics of PKSC. The study will assess the environmental impact of using palm kernel shell concrete, including its potential for reducing greenhouse gas emissions compared to conventional concrete. Laboratory tests will be conducted to determine optimum mix proportions and evaluate the influence of various factors, such as curing conditions.

II. Literature Review

A. *Compressive Strength of Palm Kernel Shells*

Palm kernel shells (PKS) are the hard outer shells of palm kernels, a byproduct of the palm oil industry, and serve as a renewable energy source with a calorific value of approximately 4,000 kcal (Kumar et al., 2017). PKS are abundant in tropical regions and are often used for heating, power generation, and biofuels. They offer advantages such as low sulfur and nitrogen content, which reduce emissions, and low ash content, minimizing maintenance needs. However, challenges include their high density, which complicates handling and transport, and the requirement for specialized combustion equipment.

In Nigeria, the government has encouraged the use of local materials in construction to reduce costs, leading to increased interest in alternative construction materials like PKS. Research has shown that PKS can be used as a partial replacement for coarse aggregate in concrete. Studies indicate that the compressive strength of concrete with PKS is generally lower than that of control concrete. For instance, Oluwafemi et al. (2019) found that 20% PKS replacement resulted in a compressive strength of 20.8 MPa, compared to 25.2 MPa for control concrete, indicating a 16.7% reduction. Similarly, Adepega et al. (2018) reported a compressive strength of 25.6 MPa for 10% PKS replacement, slightly lower than the control's 27.9 MPa.

Table II-I: Compressive Strengths of Concrete with Palm Kernel Shell from Previous Studies

Compressive Strength of Concretes with PKS	**Oluwafemi et al. (2019)**	**Adepega et al. (2018)**	**Oyedepo et al. (2019)**	**Olutoge et al. (2020)**
10%	25.6 MPa	25.5 MPa		
20%	20.8 MPa	23.6 MPa		
Compressive Strength without PKS	25.2 MPa	27.9 MPa	26.8 MPa	28.8 MPa

PKS is primarily used as fuel in some regions, but its potential as a construction material is significant. The need for sustainable alternatives in construction is pressing, as the palm oil industry generates substantial waste, including PKS, which can pose environmental hazards (Ndoka, 2006).

2.1.3 PKS as Aggregate in Lightweight Concrete

The use of PKS in lightweight concrete requires careful mix design due to its tendency to segregate in wet mixes. Abdullah (1996) emphasized the necessity of trial mixes for optimal results. Mannan and Ganapathy (2001) found that conventional mix design methods were unsuitable for PKS lightweight concrete, leading to lower than expected strengths. They proposed six acceptable mix proportions for PKS concrete, as shown in Table 2.2.

TABLE II: ACCEPTABLE MIX PROPORTION OF OPS CONCRETE REPORTED BY MANNAN AND GANAPATHY (2001)

Mix Code	Proportion by Weight of Cement (Cement = 480 kg/m³), w/c = 0.41	Demoulded Density (kg/m³)	Fresh Property (Slump, mm)	28-Day Compressive Strength (N/mm²)
E1	1.00, 0.00, 0.00, 1.71, 0.77	1890-1905	7	24.20
E2	0.90, 0.10, 0.00, 1.71, 0.77		8	22.60
E3	0.85, 0.15, 0.00, 1.71, 0.77		9	19.50
E4	1.00, 0.00, 0.5%, 1.71, 0.77		6	23.45
E5	1.00, 0.00, 1.0%, 1.71, 0.77		7	29.40
E6	1.00, 0.00, 1.5%,			

III. MATERIALS AND METHODS

The experimental studies adopted a quantitative research approach to investigate the fresh and hardened properties of concrete incorporating palm kernel shells (PKS).

A. Test Materials:

The materials used for this research include fine aggregate (river sand, designated as FA), coarse aggregate (granite, designated as CA), palm kernel shell (PKS), ordinary Portland cement (CEM II), and potable water.

i. Cement

Ordinary Portland cement (OPC CEM II) serves as the binding material in concrete, providing strength and durability. The cement content must meet the C150 standard specification for Portland cement, classified as grade M15, ensuring proper hydration and bonding of PKS particles.

ii. Water

Tap water, free from dissolved metals or ions that could inhibit the setting and hydration process, is essential for the hydration of cement and the formation of a strong concrete matrix.

iii. Palm Kernel Shell (PKS)

PKS, obtained from a palm oil mill in Ikot Osurua, Ikot Ekpene LGA of Akwa Ibom State, is lightweight, porous, and rich in lignocellulosic content. The shells will be crushed and sieved to achieve the desired particle size distribution.

iv. Granite

Granite chippings, sourced from a quarry, range in size from 4.75 mm to 20 mm.

v. Sand

River sand, obtained from the Udoh Nwankwo sand deposit near Ukana Uwa Community in Essien Udim LGA, will be dried and well-graded through a 2.36 mm sieve to fill voids between PKS particles and provide additional strength.

1) Equipment/Tools

The following equipment/tools were used:

Shovel: For mixing concrete components.

Mechanical Sieve Shaker: To agitate the sieve stack for particle separation.

Tamping Bar: For compacting concrete into cube molds.

Concrete Cube Mold: To hold concrete during curing.

Trowel: For spreading cement and plaster.

Weighing Scale: To determine the weight of samples.

Measuring Cylinder: For measuring liquid volumes.

Bowl: For containing materials like cement and aggregates.

Curing Tank: For curing concrete specimens.

Compressive Testing Machine: To test the compressive strength of concrete cubes.

Wire Mesh Bucket: For water absorption tests.

Setup for Water Absorption Test: Includes containers for water and a wire basket.

B. Methods

The structural and durability properties of PKS concrete was evaluated through various research methods, following the British Standard (BS) EN 12350 for concrete testing.

Compressive Strength Test

This test measures the ability of PKS concrete to withstand axial loads. Cube specimens (150 x 150 x 150 mm) will be tested for compressive strength using a hydraulic cube crushing machine. A total of 24 cubes will be prepared using a 1:2:4 mix proportion with a water-cement ratio of 0.5.

Split Tensile Strength Test

This test evaluates the tensile strength of PKS concrete using standard cylindrical specimens laid horizontally, with force applied radially to induce vertical cracking.

Water Absorption Test

This test determines the ability of PKS concrete to absorb water, providing insight into the internal structure of the aggregate.

Mix Design Optimization

Different mix proportions of PKS, cement, aggregates, and water will be tested to determine the optimal combination for enhancing the structural and durability properties of PKS concrete.

C. Mix Proportions

The mix design is summarized in Table 3. The adopted mix ratio is 1:2:4 with a water-cement ratio of 0.5, representative of practices in Nigeria.

TABLE III: MIX DESIGNATION

MIX	DESIGNATION	CEM	FA	CA	G	W
MC	Normal	11.57	23.14	46.29	0.00	0.55
M26	20% PKS	11.57	18.51	37.03	13.89	0.55
M30	30% PKS	11.57	16.20	32.40	20.84	0.55
M40	40% PKS	11.57	13.88	27.77	27.77	0.55

CEM = Cement, FA = Fine Coarse Aggregate ,CA = Coarse Aggregate, W = Water

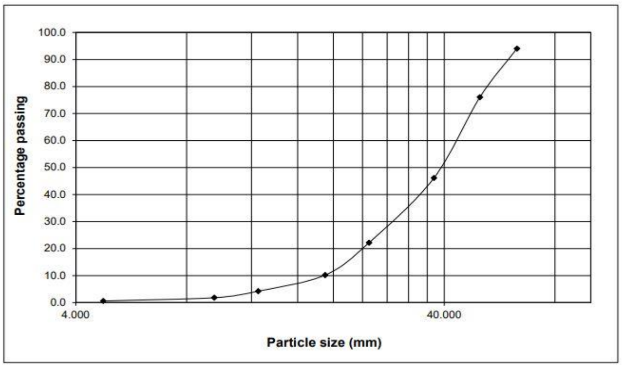
IV. RESULTS AND DISCUSSIONS

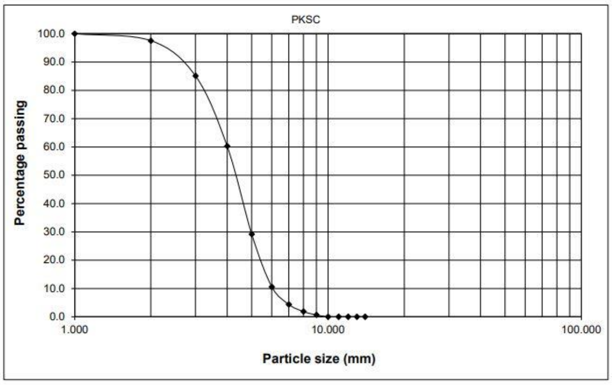
A. Preliminary Investigations

The results of preliminary investigations are summarized in Table 4.1 and illustrated in Figures 4.1, 4.2, and 4.3. The weight-based parameters, such as bulk density and specific gravity, for coarse and fine aggregates were higher than those for PKS. Conversely, PKS exhibited higher values for porosity and water absorption, indicating that it is more porous than coarse aggregate.

TABLE IV-I: PROPERTIES OF AGGREGATES, SAND, PKS, AND GRANITE

PROPERTY	CA (Granite)	PKS	FA
Bulk Density (kg/m³)	1680	1220	1796
Specific Gravity	2.70	2.54	2.71
Porosity (%)	40	48	35.00
24-hr Water Absorption (%)	1	20	2





The particle size analysis data indicate the characteristics of the aggregates. The fine aggregate has a relatively small particle size, with a coefficient of uniformity (Cu) of 2.08, suggesting a moderate range of particle sizes. The granite coarse aggregate has larger particle sizes, with a Cu of 2.31, indicating a relatively uniform distribution. The PKS coarse aggregate has intermediate particle sizes, with a Cu of 2.04, suggesting a fairly uniform distribution.

B. *Main Investigations*

1) Workability

The workability characteristics of concrete containing PKS as a partial replacement for coarse aggregate are presented in Table 4.2.

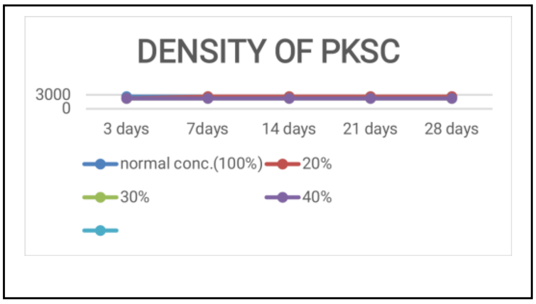
TABLE IV-2: WORKABILITY OF CONCRETE WITH PKS

% PKS in Mix	**Slump (mm)**	**Type**	**Degree of Workability**
Normal Concrete	30 mm	True	Low
20%	28 mm	True	Low
30%	26 mm	True	Low
40%	25 mm	True	Low

The results indicate that workability, as measured by slump values, decreased with increased PKS content. The high porosity and water absorption of PKS (48% and 20%, respectively) compared to coarse aggregate (40% and 1%) suggest that much of the mixing water is absorbed by PKS, reducing its availability for effective mixing. All concrete samples were classified as having very low workability.

2) Density

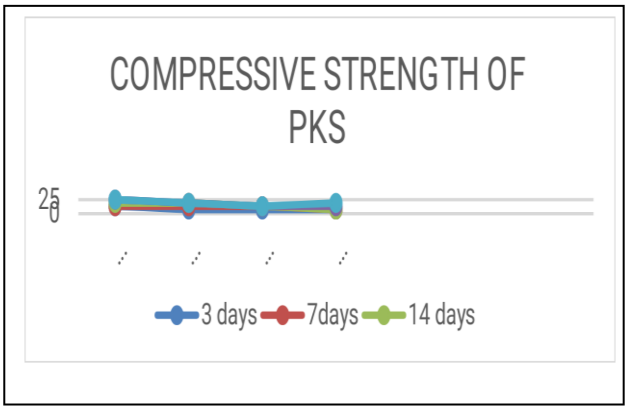
The density development of concrete specimens with PKS as a partial replacement for coarse aggregate is shown in Figure 4.3.



At 14 days of curing, the densities were 2399.5 kg/m³ for normal mix, 2256 kg/m³ for 20% PKS, 2147.5 kg/m³ for 30% PKS, and 2074 kg/m³ for 40% PKS. The decreasing density with increased PKS replacement is expected, as PKS has lower density and specific gravity than coarse aggregate. The densities of the specimens fell within the range of 2240–2480 kg/m³, indicating that concrete with up to 40% PKS can be used in conventional applications.

3) Compressive Strength

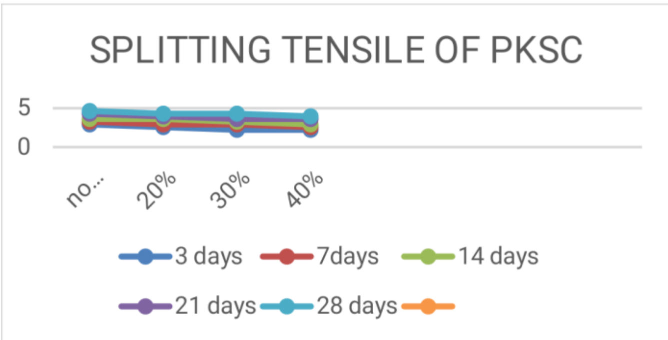
The compressive strength development of concrete containing PKS as a partial replacement for coarse aggregate is illustrated in Figure 4.4.



Normal concrete shows a steady increase in compressive strength over time, reaching 22.667 MPa at 28 days. Concrete with 20% PKS replacement starts at 4.711 MPa at 3 days and increases to 17.333 MPa at 28 days, indicating effective use of the replacement material. However, the 30% and 40% replacement mixes show significantly lower strengths, with the 40% mix reaching only 14.311 MPa at 28 days. This suggests that higher replacement rates may not be suitable for structural applications requiring high strength.

4) Splitting Tensile Strength

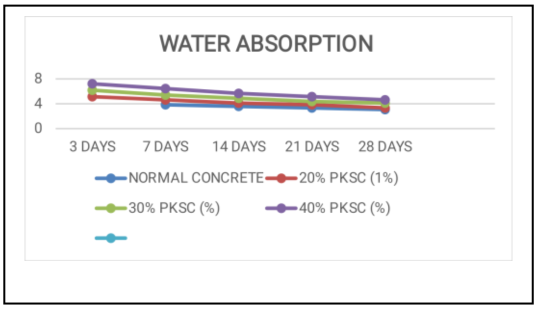
The splitting tensile strength of concrete specimens with PKS as a partial replacement is shown in Figure 4.5.

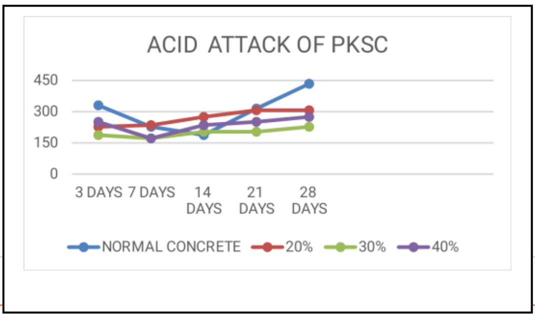


Normal concrete exhibits a steady increase in tensile strength, reaching 4.444 MPa at 28 days. The 20% PKS mix shows a slightly lower initial strength but maintains a steady increase, reaching 4.222 MPa at 28 days. In contrast, the 30% and 40% replacement mixes show lower strengths, with the 40% mix reaching only 3.778 MPa at

Water Absorption and Acid Attack in Palm Kernel Shell Concrete (PKSC)

The study evaluated water absorption and acid resistance in concrete with varying percentages of Palm Kernel Shell (PKS) as a partial replacement for coarse aggregate (0%, 20%, 30%, and 40%). Normal concrete exhibited the lowest water absorption, decreasing from 3.8% at 7 days to 2.9% at 28 days, indicating denser and less permeable hydration. In contrast, PKS concrete showed higher absorption, with 20%, 30%, and 40% replacements reaching 3.3%, 3.9%, and 4.6% at 28 days, respectively, suggesting increased porosity with higher PKS content. Similarly, acid resistance was highest in normal concrete (430 at 28 days), while 20% PKS concrete maintained stable but lower resistance (300 at 28 days). Higher PKS replacements (30% and 40%) further reduced acid resistance (222 and 269 at 28 days), indicating diminished durability. Thus, while 20% PKS replacement offers a balance between sustainability and performance, higher percentages compromise water and acid resistance, limiting their suitability for harsh environments.





V. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

A. *Summary of Findings*

The research titled "Structural and Durability Properties of Palm Kernel Shell Concrete (PKSC)" investigated the performance of concrete incorporating Palm Kernel Shell (PKS) as a partial replacement for conventional aggregates. The study evaluated structural properties (compressive strength, splitting tensile strength, and density) and durability properties (water absorption and acid resistance) of PKSC at varying replacement percentages (20%, 30%, and 40%) over curing periods of 3, 7, 14, 21, and 28 days. The findings were compared with normal concrete to assess the viability of PKSC as a sustainable alternative in construction.

Key Findings:

Compressive Strength:

Normal concrete exhibited the highest compressive strength, with significant gains between 14 and 28 days.

The 20% PKSC mix showed reasonable strength development, though lower than normal concrete.

The 30% and 40% PKSC mixes exhibited significantly lower compressive strength, making them less suitable for structural applications.

Splitting Tensile Strength:

Normal concrete had the highest splitting tensile strength, increasing steadily over time.

The 20% PKSC mix showed slightly lower tensile strength but maintained a steady increase.

The 30% and 40% PKSC mixes had lower tensile strength, with the 40% mix being the weakest.

Density:

Normal concrete had the highest density, indicating a denser and more compact structure.

The 20% PKSC mix had a lower density but remained relatively stable over time.

The 30% and 40% PKSC mixes showed further reductions in density, reflecting increased porosity.

Water Absorption:

Normal concrete had the lowest water absorption, indicating better durability.

The 20% PKSC mix had higher water absorption but showed a gradual decrease over time.

The 30% and 40% PKSC mixes exhibited significantly higher water absorption, suggesting reduced durability.

Acid Resistance:

Normal concrete demonstrated the highest acid resistance, particularly at longer curing periods.

The 20% PKSC mix showed stable acid resistance, though lower than normal concrete.

The 30% and 40% PKSC mixes had lower acid resistance, indicating reduced ability to withstand chemical attack.

B. Conclusion

The research demonstrated that Palm Kernel Shell Concrete (PKSC) can be a viable sustainable alternative to conventional concrete, particularly at a 20% replacement level. While higher replacement percentages reduce strength and durability, the 20% PKSC mix offered a balance between sustainability and performance. The study provided valuable insights for the construction industry, promoting the use of agricultural waste materials and contributing to the development of eco-friendly building practices. Further research is recommended to optimize the properties of PKSC and expand its applications in construction.

C. Recommendations

Optimal Replacement Percentage:

A 20% replacement of PKS is recommended for applications where moderate strength and durability are acceptable, offering a balance between sustainability and performance.

Higher replacement percentages (30% and 40%) should be limited to non-structural applications or environments with minimal exposure to harsh conditions.

Curing Period:

Longer curing periods (28 days) significantly improve the strength and durability of PKSC. Adequate curing should be ensured to maximize performance.

Durability Considerations:

PKSC mixes, especially at higher replacement percentages, should be used in environments with low exposure to water and acidic substances to mitigate durability issues.

Further Research:

Investigate the use of additives or treatments to improve the strength and durability of PKSC, particularly at higher replacement percentages.

Explore the long-term performance of PKSC under real-world conditions, including exposure to weathering and chemical agents.

New Knowledge

Feasibility of PKS as a Sustainable Aggregate:

The study demonstrates that PKS can be used as a partial replacement for conventional aggregates in concrete, contributing to sustainable construction practices.

A 20% replacement of PKS offers a viable alternative with acceptable structural and durability properties.

Impact of Replacement Percentage:

The research highlights the trade-off between sustainability and performance, showing that higher PKS replacement percentages (30% and 40%) significantly reduce strength and durability.

Curing and Performance:

The study emphasizes the importance of curing time in enhancing the performance of PKSC, particularly in terms of compressive strength and acid resistance.

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