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Factors Affecting Shrinkage of Periwinkle Shell Powder (PSP) Stabilized Laterised Concrete Short Column

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Abstract

This study investigates the shrinkage behaviour and strength characteristics of short columns produced from laterised concrete incorporating periwinkle shell powder (PSP) as a supplementary cementitious material. Shrinkage, a time-dependent volumetric contraction of concrete, can induce tensile stresses and cracking when restrained, thereby affecting structural durability and serviceability. Lateritic soil was used as partial replacement for conventional fine aggregate, while PSP was produced by cleaning, drying, grinding, and sieving periwinkle shells without calcination. Preliminary characterization of the constituent materials included moisture content, specific gravity, and Atterberg limit tests. Concrete mixes containing 0%, 10%, 20%, and 30% combined replacement levels of PSP and lateritic soil were prepared and evaluated for workability, compressive strength, and shrinkage deformation at curing ages. Results showed that workability increased with replacement level, with slump values of 10, 16, 25, and 30 mm at a water-cement ratio of 0.50 for 0%, 10%, 20%, and 30% replacement, respectively. Compressive strength increased with curing age, reaching 5.70, 12.00, 12.67, and 16.60 N/mm^2 at 7, 14, 21, and 28 days, respectively, for the reference trend; however, strength decreased as PSP and laterite contents increased. Conversely, shrinkage deformation increased with increasing replacement level, indicating greater susceptibility to dimensional changes. Among the modified mixes, the 10% replacement mixture at a water-cement ratio of 0.60 exhibited the best balance between strength and shrinkage performance. The findings indicate that a 10% combined replacement of cement and sand with PSP and lateritic soil is technically feasible for laterised concrete short columns, subject to appropriate mix design.

Keywords

Periwinkle Shell Powder, Concrete Shrinkage; Drying Shrinkage; Laterised Concrete; Lateritic Soil; Short Column; Sustainable Concrete; Dimensional Stability

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INTRODUCTION

Concrete undergoes dimensional changes throughout its service life. Some of these changes result from external loading and temperature variation, whereas others are caused by hydration, self-desiccation, moisture loss and carbonation. Shrinkage becomes structurally important when the free contraction of concrete is restrained. Such restraint generates tensile stress, and cracking occurs when the developed stress exceeds the tensile strength of the concrete. The use of locally available materials in concrete has received considerable attention because of the increasing cost and environmental effects of cement production, river-sand extraction, and the disposal of agricultural and marine wastes. Lateritic soil is abundant in tropical regions and can partially replace conventional fine aggregate in laterised concrete.

In addition, this substance, periwinkle shells (PS), is commonly available as seafood waste products in coastal areas of some West African Countries such as Nigeria. Figure 1 presents several types or forms of periwinkle shells. Indiscriminate disposal and mismanagement of periwinkle shells create and generate environmental pollution and sanitation problems. It is established that these shells can be utilised, reused, and processed into powder for domestic use, ash, or lightweight aggregate for construction and concrete applications.

These applications indicate that Periwinkle shell powder (PSP) and periwinkle shell ash (PSA) should not be treated as identical useful materials. PSP is known as an uncalcined product obtained through collection, cleaning, air or sun-drying, grinding, and sieving these shells, while periwinkle shell ash (PSA) is known as a product from controlled calcination followed by grinding. PSP predominantly consists of calcium-carbonate-rich material, while calcination can transform the calcium carbonate and organic constituents. In addition, calcination can transform and alter the material's reactivity, porosity of the end product, water demand and other chemical composition (Umasabor, 2019; Amarachi et al., 2021; Davies and Adigio, 2022). This distinction is significant when understanding published findings. Research and studies have demonstrated the potential and vital role of periwinkle shells as coarse aggregate and finely divided material in concrete development. Falade (1995) found and established that increasing periwinkle-shell aggregate reduced workability and modified and changed the physical and mechanical behaviour of concrete. Agbede and Manasseh (2009) similarly concluded that periwinkle shells (PS) could partially replace conventional and normal aggregate when properly proportioned, which indicates that density and strength of the final concrete will depend strongly on the replacement level. More recent research has confirmed that crushed periwinkle shells can serve as partial fine-aggregate substitutes, but performance is sensitive to their dosage and physical characteristics (Olofinnade et al., 2023).

Despite these developments, there is limited direct research on shrinkage in PSP-stabilized laterised concrete short columns. This paper therefore synthesizes evidence from studies of laterised concrete, periwinkle-shell materials and conventional concrete shrinkage to identify the factors expected to govern column behaviour and to provide a framework for experimental investigation (Maborukoje and Oyeyipo, 2007; Ghanem et al., 2024). Thus, as periwinkle shells increase in size, they retain their mollusc basic form and produce this spiral shape by continually adding shell to the edge, coiling around an imaginary axis running straight through the shell (de Brito and Kurda, 2021). The major families of periwinkles include the *Litorinae* family, which are common in North America and European shores and are widely distributed in the littoral drifts and sand banks.

The word laterite describes no material with reasonably constant properties. In temperate countries, laterite could be described as the friable clay surface. In tropical regions, laterite is the hard homogeneous, massive, clinker-like material with ferric oxide and vascular infill of soft aluminium oxides or a yellow colour and in less hilly country it could exist as very hard, soft, coarse, angular red soil. Ola, (1978), used local terminology in defining laterite soils as all products of tropical weathering with reddish-brown colour, with or without nodules or concretion but not exclusively found below a hardened ferruginous crust of hardpan. Osula (1984) defined laterite as a highly weathered tropical soil; rich in secondary oxides of a combination of iron, aluminium and manganese.

Lateritic soils are formed in hot, wet tropical regions with an annual rainfall between 750mm to 3000mm (usually in areas with a significant dry season) on a variety of different types of rocks with high iron content. The locations on the earth that characterize the condition fall in between latitudes 35°S and 35°N and. Laterite formation factors include climate (precipitation, leaching, capillary rise, and temperature) to topography (drainage), vegetation, parent rock (iron–rich rocks), and time (Ola, 1978; Antia et al., 2020). Gidigasu (1976) have identified three stages in the process of laterite formation. The first stage (decomposition) is the physio-chemical breakdown of primary minerals and release of constituent elements. The second stage is leaching under appropriate drainage conditions of combined silica and bases and relative accumulation or enrichment from outside sources of oxides and hydroxides of sesquioxides. The final stage (dehydration or desiccation) involves partial or complete dehydration (sometimes involving hardening) of the sesquioxide-rich materials and secondary minerals. With reference to the importance of short columns in concrete structures, the availability of periwinkle and periwinkle shell in some countries and the risk and impact of shrinkage on concrete structures, information and data on factors affecting shrinkage of periwinkle shell powder (PSP) stabilised laterite concrete short column are limited or not readily available. The main focus of this current study is to provide information and data on short column shrinkage and types of shrinkage, factors affecting shrinkage of periwinkle shell powder (PSP) stabilized laterised concrete short column

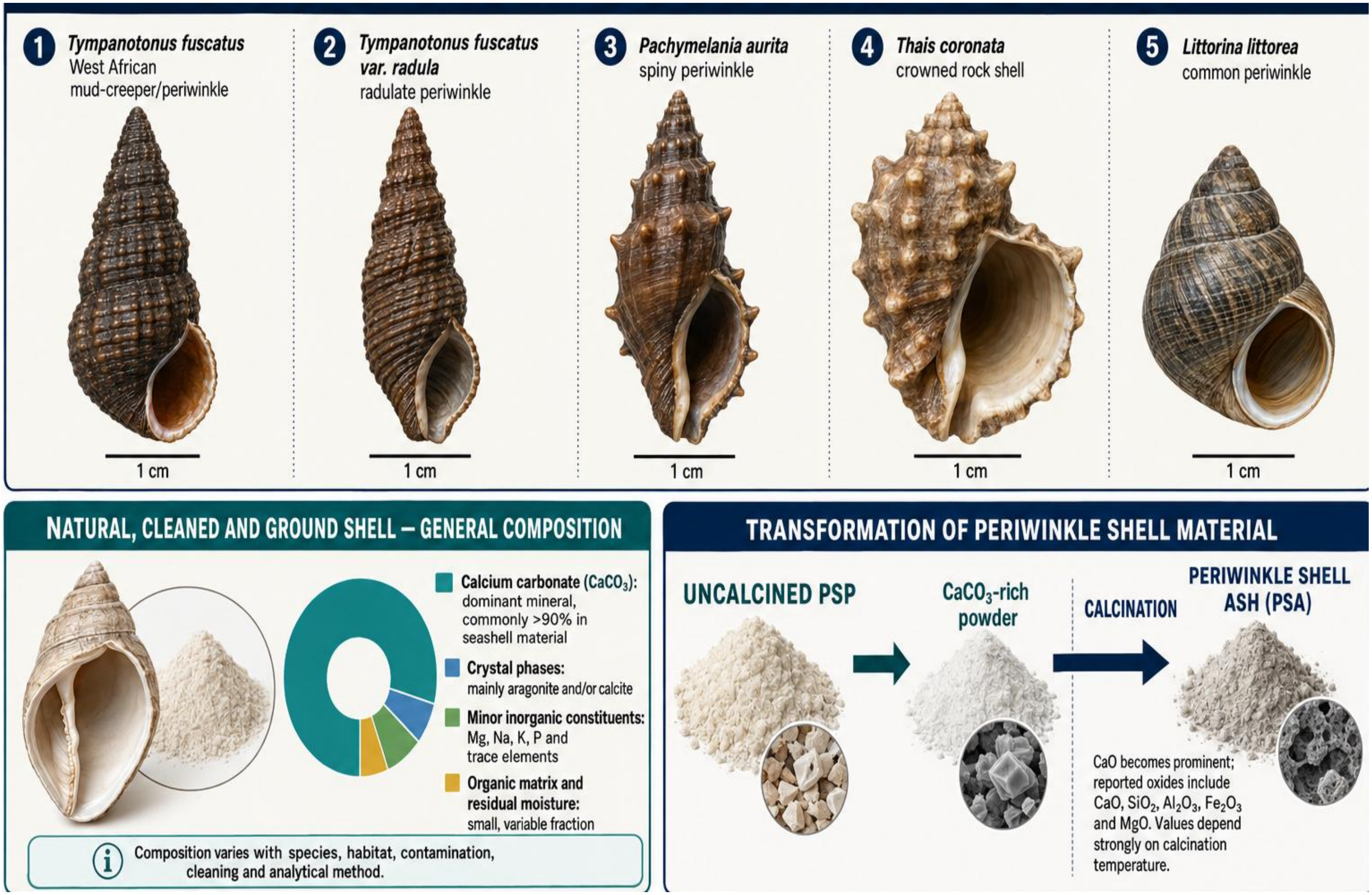

Figure 1: Several possible types of periwinkle shells (Adopted from Oke et al., 2022a and b; Omiogbemi et al., 2026) .

MATERIALS AND METHODS

In the preliminary study, a desktop review was conducted on the previous studies between 1900 and 2025. On the previous studies, comparisons were made on the findings, techniques used, and the limitations. In the field study the materials used for this research work include: cement, aggregate, laterites, periwinkle shell powder and water. Ordinary Portland cement was purchased from a cement dealer in Ile-Ife. Sand was purchased from local quarry in Ile-Ife. The portions of sand passing through sieve size 4.75 mm were used for the study. Granite was also gotten from the Agricultural Engineering Department extension that was under construction.

The portions of granite passing through sieve size 20mm and retained on 5 mm were used. Periwinkle Shells were obtained from Adaranijo market in Lagos State. The periwinkle shells were ground to powder in a mill in Lagos State. The particle size of PSP passing sieve 300 micro mm was used for the study. Laterites were obtained from ETF Hostel of Obafemi Awolowo University. The portions of laterites passing through sieve size 4.75mm were used for the study. Preliminary analyses such as sieve analysis, moisture content test, specific gravity test, and slump test were carried out on the samples.

Four different percentages of replacement of PSP and lateritic soils (0%, 10%, 20% and 30%) were used for the compressive strength and shrinkage deformation tests. Zero percentage (0%) replacement of PSP and laterites was the control mix, while the remaining percentages were used to determine the optimum replacement level for each of the tests, respectively. Two different water-binder ratios were used for the compressive strength test and shrinkage deformation test. The laboratory measurement of the shrinkage deformation is already designed with a loading and measuring rig. The shrinkage test rig is made up of a simple steel frame with an adjustable height beam to hold in place the measuring gauge calibrated to read to the nearest 0.01mm. This arrangement was placed on top of the 100x100mm rectangular plate (ASTM, 2014) Ikede and Alfred, 2004). The compressive strength test was then carried out on each of the hardened concrete based on their curing ages. The strain or the shrinkage was computed using equation (1) as follows:

$$\varepsilon_{sh} = \frac{\Delta L}{L_i} \tag{1}$$

Where; where $\Delta L$is the measured length change ($L_i - L_f$); L_i is the initial length of the column and L_f is the final length of the column and $L_i$is the original length of the column. Plate 1 shows the laboratory setup of shrinkage deformation measurement. A total of 96 concrete cubes of size 100 x 100 x 100 mm were cast using a concrete mix of 1:2:4 and a water binder ratio ranging from 0.5 to 0.6. The 0% phase (without addition of PSP and laterite) serves as the control concrete mix, while different percentages of PSP and laterite (10%, 20%, and 30%) were used to replace cement and fine aggregate in concrete by following the same procedure as that of the control mix.

After a period of 24 hours, the mould was stripped off the cubes, and the cubes were cured to prevent loss of moisture. In Flexural strength determination, which is one of the methods of assessing the tensile strength of concrete. It gives a measure of tensile strength in bending. The standard size of specimen used is 500mm x 100mm x 100 mm; aggregates not more than 20mm were used. The same procedure for preparing the concrete cubes for the compressive strength test was used for the flexural strength test. A load was applied on the machine through two rollers at the third point of the span until the specimen broke. A total of 8 columns were cast using the different percentages of PSP and laterites as mentioned earlier. Figure 2 shows the flowchart of the materials and methods used.

RESULTS AND DISCUSSION

Results and discussion from this study are presented and discussed as follows: Desktop review, which consists of the following vital elements.

a. **Forms of shrinkage:** Various forms of shrinkage relevant to short columns are presented as:

- **Plastic shrinkage**: Plastic shrinkage occurs before concrete has completely hardened. It develops when the rate of surface-water evaporation exceeds the rate at which bleeding water rises to the surface. High temperature, low relative humidity, direct sunlight and high wind velocity increase the risk. Although columns have lower exposed horizontal surfaces than slabs, plastic shrinkage may occur at the column head and on surfaces exposed immediately after formwork removal. Laterite and finely ground PSP may reduce bleeding because of their high surface areas. Reduced bleeding can be beneficial for stability, but it also means that surface moisture may not be replenished adequately during hot or windy placement conditions.
- **Chemical and autogenous shrinkage:** Chemical shrinkage results from the absolute volume of hydration products being lower than the combined volume of cement and water before hydration. Autogenous shrinkage is the externally observable contraction associated principally with self-desiccation in a sealed cementitious system. These processes are particularly relevant to mixtures with low water-to-binder ratios or high binder contents. A comprehensive review by Ghanem et al. (2024) shows that water-to-binder ratio, cement chemistry, supplementary materials, internal curing and curing temperature influence chemical and autogenous shrinkage (Ghanem et al., 2024).

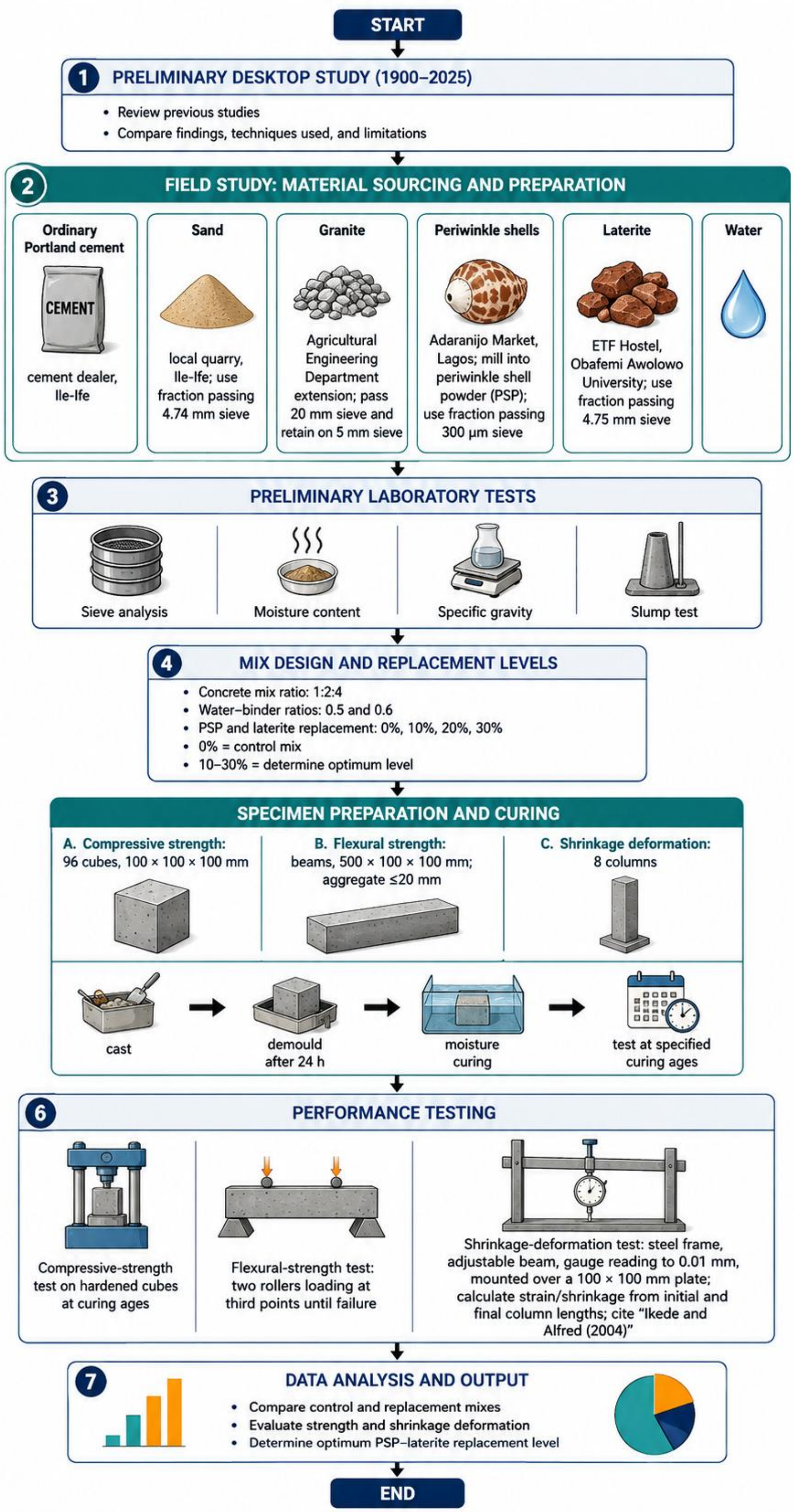

Figure 2: The flowchart of the materials and methods used.

Plate 1: Laboratory setup of shrinkage deformation measurement

- **Drying shrinkage:** Drying shrinkage occurs when hardened concrete loses moisture to an unsaturated environment. The removal of water from capillary and gel pores produces capillary tension, disjoining-pressure changes and surface-energy changes within the hydrated paste. Drying shrinkage is generally the dominant long-term shrinkage component in ordinary reinforced concrete short columns.
- **Carbonation shrinkage**: Carbonation shrinkage results from reactions between atmospheric carbon dioxide and hydration products, particularly calcium hydroxide. Its effect is greatest at intermediate relative humidity, where sufficient moisture and carbon dioxide are simultaneously present. The porous surface layers of poorly compacted laterised concrete may be more susceptible to carbonation and associated contraction.

b. **Factors affecting shrinkage:** The key and vital factors that influence shrinkage are as follows:
   - **Laterite replacement level:** The proportion of conventional sand replaced with lateritic soil is one of the most influential variables. Laterite normally contains higher quantities of fines, iron and aluminium oxides, and clay minerals than river sand. These particles possess

relatively high specific surface areas and can absorb or retain considerable amounts of water. Salau (1998) reported that the shrinkage strain of laterised concrete was several times greater than that of conventional concrete, depending on the laterite content. The study suggested that approximately 25% laterite replacement could be used without causing excessive shrinkage (Salau, 1998).

Increasing the laterite content beyond an optimum level can increase shrinkage through: greater water demand; increased fine and clay contents; a reduced proportion of rigid quartz sand; a higher volume of paste-like material; increased porosity when compaction is inadequate; and greater sensitivity to wetting and drying. Recent research also shows that increasing laterite replacement can reduce compressive, flexural and splitting tensile strengths, particularly at relatively high replacement levels (Ukpata et al., 2024). A reduction in tensile strength is important because it lowers the resistance of the column to shrinkage-induced cracking.

Laterite mineralogy and plasticity: Lateritic soils are highly variable. Two laterite samples obtained from nearby locations may have substantially different clay contents, plasticity indices, mineral compositions and water absorptions. Kaolinite-dominated laterites generally undergo smaller moisture-related volume changes than laterites containing appreciable quantities of expansive clay minerals. High liquid limit and plasticity index commonly indicate a greater quantity or activity of clay-sized material. These properties can increase water demand and moisture-sensitive deformation. Laterite should therefore be characterized using particle-size distribution, Atterberg limits, specific gravity, moisture content, X-ray diffraction, X-ray fluorescence or SEM–EDX before it is adopted for structural concrete (Robert et al., 2023; Etim et al., 2022).

PSP content: The effect of PSP depends on whether it replaces cement, sand, laterite or another constituent. The replacement basis must always be specified by mass or volume. At a low or moderate dosage, well-ground PSP may fill voids among cement and aggregate particles. This filler effect can improve packing density, reduce interconnected pores, and potentially reduce moisture loss. At excessive replacement levels, however, PSP can increase shrinkage because fine particles of PSP increase the total specific surface area; additional mixing water may be required to maintain workability; the effective cement content may be reduced if PSP replaces cement; particle agglomeration may create weak or porous zones; insufficient paste may remain to coat the aggregate; and elastic modulus and tensile strength may decrease. Research and studies on PSP-stabilized lateritic soil revealed that maximum dry density (MDD) of laterite soil improves up to an optimum PSP content of 6%, after which the benefit (MDD) diminishes. Similarly, PSP increased the optimum moisture content of the laterite soil, which demonstrates the influence of PSP on water demand (**Dauda et al., 2018**).

Although compacted laterite soil and concrete are different materials and systems, these results indicate that PSP dosage should be optimized rather than increased indiscriminately.

PSP particle size, shape and surface texture: Finely ground or fine aggregate of PSP can enhance packing or reduce volume and act as a nucleation surface for hydration products. However, a very fine powder or aggregate has a large surface area, which can absorb, remove or adsorb more water. In addition, additional water to the concrete compensates for the resulting loss of workability, which may increase drying shrinkage. Coarser aggregate of PSP or poorly ground particles of PSP may behave as weak fine aggregate rather than filler in the concrete. These aggregates can create irregular interfacial transition zones and stress concentrations in the end products.

Uniform grinding and sieving of PSP are therefore necessary in the utilization of PSP as a replacement. Furthermore, particle-size distribution should preferably be determined using either sieve analysis or laser diffraction (LD), while morphology should be assessed through scanning electron microscopy (SEM).

PSP composition and processing: Periwinkle shells (PS) are known to consist mainly of calcium carbonate in crystalline forms. The crystalline form can be either aragonite or calcite, with minor quantities of organic matter and other metals or minerals, which indicates that washing or cleaning can remove salts, soil, and decaying tissue that could interfere with cement hydration. In addition, proper drying of PSP can prevent uncontrolled moisture from affecting the effective water-to-binder ratio (WBR).

Grinding conditions also influence morphology and fineness. If calcination is used, the product should be described as periwinkle shell ash rather than PSP. Studies of seashell powders show that their influence depends on mineralogy, particle size, thermal treatment and replacement level (Wang et al., 2020; Bamigboye et al., 2020).

Water-to-binder ratio and total water content: Total mixing water is among the most important factors controlling drying shrinkage. Water not consumed during hydration eventually occupies capillary pores and may evaporate. A high water-to-binder ratio normally produces a more porous paste and a greater quantity of evaporable water. The situation is particularly serious in laterised concrete because both laterite fines and PSP may reduce slump. Adding water at the construction site to restore workability can substantially increase shrinkage. A compatible water-reducing or super-plasticizing admixture is preferable to uncontrolled water addition. Falade et al. (2017) investigated laterised concrete and found that the use of a superplasticizer reduced shrinkage by lowering the quantity of evaporable water. The 90-day shrinkage values of the materials were approximately 180, 1700, 1600 and 1500×10^{-6} for concrete made with 12.5-mm aggregate, 12.5-mm aggregate plus superplasticizer, 19-mm aggregate and 19-mm aggregate plus superplasticizer, respectively (Falade et al., 2017).

Cement and paste contents: Shrinkage occurs predominantly in the cement paste, while aggregates restrain paste contraction. Therefore, concrete containing a high paste volume generally exhibits greater shrinkage than a well-proportioned mixture containing an adequate volume of stable aggregate. Treatment of PSP as an additional fine material without adjusting the mix volume, the total powder or paste demand may increase. Conversely, replacing too much cement with relatively inert PSP can reduce hydration products, stiffness and tensile capacity. Both effects can increase the risk of cracking. Mixture optimization should consequently be carried out on an absolute-volume basis.

Aggregate content, type and maximum size: Rigid coarse aggregate restrains the contraction of the surrounding cementitious matrix. Concrete containing a greater volume of sound, stiff and well-graded aggregate generally shrinks less than paste-rich concrete. Aggregate mineralogy and elastic modulus also influence the degree of restraint. Larger maximum aggregate sizes may permit a reduction in paste and water demand. In the study by Falade et al. (2017) laterised concrete containing 19-mm aggregate exhibited lower drying shrinkage than the corresponding mixture containing 12.5-mm aggregate (Falade et al., 2017). In addition, aggregate size must be a key factor for the end product to remain compatible with column dimensions, reinforcement spacing and concrete cover to avoid segregation and honeycombing.

Grading and packing density: It has been established that a well-graded sand, laterite, PSP and coarse aggregate will produce a dense particle skeleton with fewer voids. This system reduces the amount of paste necessary to fill the voids and improves aggregate restraint. However, poor grading of aggregate increases pastes demand, porosity and shrinkage. The ratio of coarse-to-fine aggregate is therefore important in the quality of the concrete. Experimental results and evidence indicate that aggregate proportions affect both the magnitude and development of drying shrinkage (Abbasi and Hogg, 2021; Abbasi et al., 2021), which indicates that packing trials should be performed to identify a combination of laterite, sand and PSP that produces minimum void content without compromising workability.

Workability, mixing and compaction: Laterised concrete usually has lower workability than conventional or traditional concrete at the same water content. This is because lateritic fines particles absorb water and increase internal friction. In addition, PSP can further reduce slump when its particles are fine or angular in shape. Insufficient mixing can cause non-uniform PSP distribution and local variation in water and cement contents of the concrete. It is well established that poor compaction will produce entrapped air, honeycombing, and connected pores through which moisture can escape rapidly, which indicates that excessive vibration of the concrete may cause segregation. In this condition and situation, controlled mechanical mixing and appropriate vibration are therefore required to achieve a reliable system.

Curing method and duration: Curing of concrete affects hydration, pore structure, tensile strength and moisture gradients, while inadequate curing of the same interrupts hydration and allows rapid moisture loss from the surface of the material (Etim et al., 2021). These specific actions produce large early-age shrinkage gradients and increase cracking susceptibility of the structure. In addition, extended moist curing of the same material generally improves its hydration and reduces permeability. These factors of curing and duration of curing final have an effect on measured drying shrinkage and depend on the selected reference age. This occurs because well-cured concrete contains more hydrated paste when drying begins. Nevertheless, adequate curing usually reduces harmful early-age cracking and improves resistance to restrained shrinkage. It should be noted that water curing, wet coverings or curing compounds should be applied immediately after formwork removal.

Relative humidity, temperature and wind: It is well established that drying shrinkage of concrete materials increases as environmental conditions such as relative humidity decrease. At high temperatures and relatively high wind speed, moisture evaporation, which can increase early shrinkage of the material. Furthermore, wet and dry conditions may generate cyclic shrinkage and swelling, progressively damaging the paste–aggregate interfaces. These effects are especially important and critical in tropical climates, where short columns may be cast during periods of high temperature and intense solar radiation. Column specimens intended for comparative research should be stored under controlled temperature and relative humidity.

Column dimensions and surface-area-to-volume ratio: Moisture leaves or evaporates from concrete through exposed surfaces. Small columns and specimens with high surface-area-to-volume ratios can dry faster, which can usually develop shrinkage more rapidly than large sections. The speculative size of a member, often represented by twice the cross-sectional area divided by the drying perimeter, is therefore central to shrinkage prediction. A short column may have limited slenderness but can still experience significant shrinkage due to its surface. Its cross-sectional dimensions and number of exposed faces that determine or determine the rate of moisture movement. Sealing some surfaces or leaving the surfaces in contact with formwork changes the drying boundary conditions and must be documented for further studies.

Reinforcement ratio and restraint: Longitudinal reinforcement restrains free concrete shrinkage. Consequently, the measured shortening of a reinforced column is usually lower than the free shrinkage of an unreinforced specimen made from the same concrete. However, restraint produces tensile stress in the concrete and compressive stress in the reinforcement. A higher reinforcement ratio increases internal restraint but may promote more numerous, closely spaced cracks if the concrete tensile capacity is insufficient. End connections, foundations and beams provide additional external restraint. Free-shrinkage measurements alone therefore cannot completely describe the behaviour of a structural column.

Column loading and creep interaction: Short columns principally carry axial compression. Sustained compression produces creep, which causes additional shortening, but it may also relax some tensile stress generated by restrained shrinkage. Measured deformation in a loaded column is thus a combination of elastic strain, creep, shrinkage and thermal strain:

$$\varepsilon_{\mathbf{total}} = \varepsilon_{\mathbf{elastic}} + \varepsilon_{\mathbf{creep}} + \varepsilon_{\mathbf{shrinkage}} + \varepsilon_{\mathbf{thermal}}. \quad (2)$$

Where: ϵ_{total} is the total strain or shrinkage $\epsilon_{elastic}$ is the strain or shrinkage due to elastic; ϵ_{creep} is the total strain or shrinkage due to creep; $\epsilon_{shrinkage}$ is the total strain or shrinkage due to shrinkage; and ϵthermal is the total strain or shrinkage due to thermal or temperature change. Temperature and load-related strains must therefore be evaluated differently or isolated from others when the objective is to determine shrinkage.

Age at drying and duration of observation: Concrete exposed to drying soon after casting generally shrinks more rapidly than concrete subjected to prolonged moist curing. Shrinkage continues for months or years, although its rate decreases with time. Short-duration tests may therefore underestimate ultimate shrinkage. Measurements should be taken at frequent intervals during the early period and continued for at least 90 days; longer periods of 180 or 365 days are preferable for model development.

c. Expected interactions among the Factors affecting shrinkage

The factors do not operate independently. Their interactions can be more important than their individual effects. The interaction can be summarised as presented in Table 2. Thus, it should not be assumed that PSP automatically increases or decreases shrinkage. Its effect depends on dosage, fineness, replacement basis, mixture water, laterite properties and curing.

d. Comparative Review of Previous Studies on the Characterization of Periwinkle-Reinforced Concrete, 1900–2025

In concrete research, periwinkle shells have been used in four principal forms as follows:

- Whole or crushed shells as partial or complete coarse-aggregate replacement.
- Crushed or pulverized shells as fine-aggregate replacement.
- Periwinkle shell ash (PSA) as partial cement replacement.
- Periwinkle shell powder (PSP), without calcination, as filler or partial cement/fine-aggregate replacement.

In summary, most studies concern periwinkle-modified concrete rather than conventional reinforcement. Only a smaller group investigated steel-reinforced beams, textile-reinforced concrete or fiber-containing composites. No verifiable experimental publication specifically addressing periwinkle-shell concrete was located for 1900–1973. The documented studies and research on PSP and PS appear to have started with Orangun (1974) investigation, the study and research expanded considerably after with Falade (1995). Table 3 presents a comparative summary of previous studies on PSP and PS. From the table, the literature or the studies on these PSP and PS can be divided or grouped into five broad stages or phases as follows:

- **1900–1973: pre-investigation period**: In the case there is no directly verified periwinkle-shell concrete or PSP application studies were identified.
- **1974–1999: feasibility stage**: In the stage, Orangun (1974) and Falade (1995) established that periwinkle shells could function as lightweight coarse aggregates. These studies conducted the characterization and concentrated on density, compressive strength, modulus of rupture, and elastic modulus of the PSP and PS applications to concrete.
- **2000–2010: partial-replacement stage**: In this category, research and studies by Basuri et al. (2018); Agbede and Manasseh (2009) and Afolayan et al. (2018) evaluated shell–granite or shell–gravel combinations. Research and studies here increasingly recognized that partial replacement of conventional aggregates was more practical than complete substitution of these aggregates.
- **2011–2020: ash, durability and optimization stage**: In this case, the field expanded from shell aggregates to PSA as a cement substitute were the key and main focus or issue. Researchers and engineers investigated splitting-tensile strength, sulphate and acid resistance, accelerators, curing methods and techniques and statistical optimization of PSA and PSP.
- **2021–2025: advanced and hybrid characterization stage**: Recent and emerging studies and works have included nanosized PSA, polymer concrete, quarry-dust–PSA–fibre composites, basalt-textile reinforcement, predictive models, paving stones, carbonated PSA and masonry products as applications of the PSA, PSP and PS.

f. Periwinkle Shell and Chemical Composition of Periwinkle Shell Powder and Periwinkle Shell Ash

The chemical composition of periwinkle shell materials varies with shell species, geographical source, washing, grinding, calcination temperature and analytical method. The values in Table 4 report oxide compositions obtained mainly by X-ray fluorescence analysis. Figure 3 shows the trend and pattern of publications globally and in Africa.

Table 2: Interaction of Factors affecting shrinkage

Interaction	Likely effect on shrinkage
High laterite content + high water content	Increased porosity and drying shrinkage
Very fine PSP + constant slump achieved by adding water	Increased water demand and shrinkage
Moderate PSP + optimized grading	Improved packing and potentially reduced shrinkage
High PSP replacing cement	Reduced stiffness and tensile strength; increased cracking risk
Low water-to-binder ratio + high binder content	Lower drying shrinkage but potentially higher autogenous shrinkage
Larger aggregate + adequate compaction	Greater restraint and lower drying shrinkage
Inadequate curing + hot, dry exposure	Rapid moisture loss and early cracking
High reinforcement ratio + weak concrete	Reduced free shortening but increased restraint stress
Small column section + several exposed faces	Faster moisture loss and earlier shrinkage development

Table 3: Comparative summary of previous studies

Period/study	Periwinkle material and application	Characterization methods	Principal findings	Major and Key limitations
1900–1973	No verified periwinkle-concrete study identified	—	This period represents the pre-development stage of the subject. Research on lightweight concrete existed, but periwinkle-shell utilization was not documented in the reviewed literature.	Absence and lack of searchable or digitized records do not prove that no informal research experimentation occurred.
Orangun (1974)	Whole periwinkle shells as coarse aggregate	Aggregate properties, compressive strength, modulus of elasticity and modulus of rupture	The study established and revealed that shell strength controlled concrete strength of the product. Although stiffness and rupture strength were lower than those of traditional concrete such as gravel concrete, strengths considered adequate for some structural applications were obtained.	Limited information and data on durability, reinforcement interaction, shell treatment, preservation and microstructure; early mix-design and testing standards were utilised.
Falade (1995)	Partial and complete replacement of	Shell unit weight, density, compressive strength and flexural strength	Unit weight PSW was approximately 694 kg/m³. Increasing the content of PS reduced the compressive and flexural	No data and information on SEM, XRD or interfacial transition-zone analysis; limited

Period/study	Periwinkle material and application	Characterization methods	Principal findings	Major and Key limitations
	granite by periwinkle shells		strengths. Concrete with 100% PS behaved as lightweight concrete, with reported 28-day strengths of between 11.77 and 15.65 MPa.	durability and long-term deformation evaluation and assessment.
Dahunsi (2003)	Periwinkle–granite aggregate concrete	Physical properties, workability, density and compressive-strength development	The products demonstrated that periwinkle shells could partially replace granite in concrete development and that the blended shell–granite concrete performed better than concrete containing shells only.	Limited publicly accessible methodological details; durability and microstructural mechanisms were not extensively evaluated.
Agbede and Manasseh (2009)	Shells as partial or complete river-gravel replacement	Bulk density, aggregate-impact value, workability, concrete density and compressive strength	The Shell bulk density was 515 kg/m³, compared with 1,611 kg/m³ for gravel. Shell aggregate had a high impact value of 58.59 % reduction. Concrete containing 100% shells produced a density of about 1,944 kg/m³ and 28-day strength of 13.05 MPa.	High impact value indicated weak aggregate. The study focused mainly on compressive strength, without detailed durability, bond or structural testing.
Olusola and Umoh (2012)	PSA replacing cement at up to 40%	Chemical composition, compressive strength and splitting-tensile strength up to 180 days	Strength of concrete increased with curing age but generally decreased as PSA content increased. Lower PSA levels produced more acceptable performance than high-content replacement of granite.	Calcination conditions and particle characteristics were not comprehensively linked with strength; limited microstructural characterization.
Umoh and Olusola (2013)	PSA-blended concrete exposed to magnesium sulphate	Compressive strength under sulphate exposure	Approximately 10% PSA was reported as an effective replacement level under magnesium-sulphate exposure, while higher PSA contents generally reduced strength.	Durability evaluation relied strongly on residual compressive strength; mass change, expansion, mineral phases and pore structure were insufficiently characterized.
Otunyo et al. (2013)	Crushed shells replacing river gravel	Aggregate properties, workability, density and compressive strength	Confirmed that shell concrete was lighter and weaker than gravel concrete.	Findings largely confirmed earlier studies; limited innovation in chemical,

Period/study	Periwinkle material and application	Characterization methods	Principal findings	Major and Key limitations
			Increasing gravel content improved workability, density and strength.	microscopic and durability characterization.
Ameh et al. (2014)	Periwinkle shells used as fine and coarse aggregates	Specific gravity, particle grading, density and cube compressive strength	Partial replacement, particularly at relatively low levels, produced concrete with lower density and potentially usable strength. High replacement substantially reduced strength.	Only cube behaviour was emphasized; limited testing of elastic modulus, tensile strength, permeability and structural members.
Umoh and Ujene (2015)	High-volume PSA-blended cement concrete containing sodium nitrate	Compressive and splitting-tensile strength	Sodium nitrate accelerated strength development. The authors reported favourable results for a mixture containing approximately 30% PSA and 2% $NaNO_3$ compared with equivalent PSA concrete without accelerator.	The long-term effects of the chemical accelerator, reinforcement corrosion and field exposure were not established.
Umasabor and Okovido (2018)	Periwinkle-shell concrete subjected to different curing methods	Workability, density and compressive strength under alternative curing regimes	Both shell percentage and curing method significantly affected strength. Proper water curing produced better strength development than less effective curing methods.	Short testing period and limited durability indicators; no detailed pore-structure or shell–paste interface characterization.
Dahiru et al. (2018)	Periwinkle and palm-kernel shells as alternative aggregates	Aggregate properties, density, workability and strength	Both agricultural/marine shell aggregates reduced concrete density. Periwinkle-shell mixtures demonstrated potential for lightweight applications at controlled replacement levels.	Combining two shell types complicated direct attribution of performance; long-term and reinforced-member behaviour were not established.
Umoh et al. (2013); Umoh and Ujene (2015); Eziefula et al. (2017); Umoh and Olusola (2012)	PSA-blended concrete in sulphuric-acid environments	Compressive strength at different acid concentrations, PSA levels and ages; ANOVA	Sulphuric acid, PSA content and exposure age significantly affected strength. PSA did not eliminate the adverse effect of acid attack, particularly at high replacement levels.	Acid durability was assessed mainly through strength; chemical degradation products and microcracking were not sufficiently investigated.
Oladiran et al. (2020)	Periwinkle and palm-kernel shells	Slump, density, compressive strength and splitting-tensile strength	Moderate replacement produced usable lightweight concrete, whereas high replacement reduced density and	Limited durability testing and inadequate separation of

Period/study	Periwinkle material and application	Characterization methods	Principal findings	Major and Key limitations
	replacing granite at 0–100%		mechanical strength because of the weaker, smoother and more porous shell aggregate.	surface texture, absorption and aggregate-strength effects.
Ruslan et al. (2021)	Review of shells used as aggregate and PSA used as cement replacement	Comparative literature review	Concluded that controlled replacement could reduce waste and concrete self-weight, but performance depended strongly on cleaning, grinding, calcination, particle size and replacement percentage.	Relied on heterogeneous studies with different mix designs and test methods; no quantitative meta-analysis.
Odeyemi et al. (2020)	Periwinkle-shell polymer concrete	Density, compressive strength, flexural strength and thermal exposure	Average density was approximately 1,510 kg/m^3. Seven-day compressive strength was about 59–61 MPa, but strength progressively decreased after exposure to 50–100°C.	Polymer concrete is not directly comparable with Portland-cement concrete; limited ageing, fire, economic and environmental assessment.
Ugwu and Egwvagu (2022)	Mashed periwinkle shells replacing fine aggregate at 0–100%	Sieve analysis, specific gravity, compressive strength and nonlinear regression	Low-to-moderate replacement was more favourable than high replacement. The regression model related shell content to compressive strength.	Model validation was limited to the experimental dataset; water absorption, durability and microstructure were not thoroughly evaluated.
Aliyu et al. (2022)	Re-vibrated periwinkle-shell concrete	Compressive strength and nondestructive parameters	Demonstrated relationships between strength and nondestructive measurements and showed that re-vibration could influence consolidation and strength.	Predictive relationships were based on a restricted range of mixtures and require independent validation.
Olofinnade et al. (2023)	Crushed periwinkle-shell waste replacing sand in stone-dust concrete	Particle properties, fresh density, hardened density, water absorption, compressive and splitting-tensile strengths	Controlled shell substitution produced potentially useful eco-concrete, while excessive replacement increased porosity and reduced strength.	Limited evaluation of drying shrinkage, creep, chloride penetration, reinforcement bond and service-life performance.
Nwa-David (2023)	Nanosized PSA as partial cement replacement under	Particle-size modification, curing comparison and compressive strength	Nanosizing improved surface area and potential reactivity; strength remained	Limited mineralogical and durability evidence; energy demand and cost of producing

Period/study	Periwinkle material and application	Characterization methods	Principal findings	Major and Key limitations
	different curing conditions		dependent on replacement level and curing condition.	nanosized ash were not quantified.
Adah et al. (2024)	PSP as filler in polymer-matrix composites	Mechanical characterization of PSP-filled composites	Demonstrated that particle loading and polymer type strongly influenced composite strength and stiffness.	The matrix or material was polymeric rather than Portland-cement concrete; therefore, findings cannot be transferred directly to conventional or traditional concrete.
Njoku et al. (2025)	Quarry dust and PSA in concrete containing sisal fibres	Physical and chemical characterization, slump, density, compressive and tensile-related properties	A compressive strength of up to approximately 28.8 MPa was reported for an optimized combination of quarry dust, PSA and sisal fibre. Hybrid waste utilization improved sustainability potential.	Multiple variables—quarry dust, PSA and sisal fibres made product difficult to isolate the individual contribution of PSA; and long-term durability of the end product remained uncertain.
Chiadighikaobi and Ubani-Wokoma (2025)	Granite–periwinkle lightweight concrete reinforced with basalt textile	Compressive strength, flexural/structural response, cracking, load and deflection behaviour	Basalt textile improved the load-resisting capacity and crack control of lightweight periwinkle concrete, partly compensating for its relatively low tensile performance.	Limited number and dimensions of structural specimens were used; long-term textile–matrix bond, creep, shrinkage and environmental resistance of the product are required for investigation.
Sonibare and Okesoto (2025)	Crushed shells used in concrete paving stones	Physical properties, water absorption, density, compressive strength and replacement-level comparison	Low shell contents showed potential for economical non-structural paving applications; excessive replacement reduced strength and increased absorption.	Results apply principally to paving units, not reinforced columns or beams; abrasion and long-term field performance require additional study.
Saeed et al. (2025)	Carbonated PSA as supplementary cementitious material	Carbonation treatment, chemical/mineral characterization and cementitious-performance tests	Carbonation was used to stabilize calcium-rich ash and potentially store CO_2 while producing a supplementary cementitious material.	Emerging laboratory-scale technique; processing energy, scalability, embodied carbon and long-term concrete durability remain to be demonstrated.

Period/study	Periwinkle material and application	Characterization methods	Principal findings	Major and Key limitations
Olofinnade et al. (2025)	Periwinkle and palm-kernel shells in load-bearing masonry units	Density, absorption, compressive performance and masonry suitability	Controlled shell incorporation produced lighter masonry products with potential for low-rise and noncritical applications.	Masonry-unit results cannot be directly applied to reinforced structural concrete; full-scale wall and long-term exposure studies are required.

Table 4: Comparative oxide composition (Source: Umoh, 2020; Offiong and Akpan, 2017; Oke et al., 2022)

Chemical constituent	Formula	Periwinkle shell powder, uncalcined (%)	Periwinkle shell ash (%)	PSA, 600–800°C (%)	PSA at 600°C (%)	PSA at 800°C (%)	PSA at 1000°C (%)
Silicon dioxide	SiO_2	16.87	17.50	33.84	23.32	33.85	30.80
Aluminium oxide	Al_2O_3	10.87	8.65	10.20	9.62	10.24	10.84
Iron(III) oxide	Fe_2O_3	1.92	2.31	6.02	5.01	6.25	5.58
Calcium oxide	CaO	52.80	54.31	40.84	38.62	40.63	46.39
Magnesium oxide	MgO	6.72	6.59	0.48	0.36	0.83	0.73
Sodium oxide	Na_2O	2.34	3.82	0.24	0.24	0.15	0.27
Potassium oxide	K_2O	2.56	4.25	0.14	0.13	0.26	0.27
Sulphur trioxide	SO_3	NR	NR	0.26	0.15	0.25	0.18
Titanium dioxide	TiO_2	NR	NR	0.03	0.02	0.05	0.23
Phosphorus pentoxide	P_2O_5	NR[1]	NR	0.01	0.01	0.01	0.00
Manganese(III) oxide	Mn_2O_3	NR	NR	0.00	0.00	0.00	0.00
Loss on ignition	LOI	NR	NR	7.60	22.50	7.08	6.28
SiO_2 + Al_2O_3 + Fe_2O_3	—	29.66	28.46	50.06	37.95	50.34	47.22

[1] **NR = not reported in the cited source**

Figure 3a: Global Trend and Pattern of Publications on factors affecting shrinkage of PSP -stabilized laterite concrete short column between 1900 and 2025 (Adopted from Umoh et al., 2013; Umasabor 2019; Robert et al., 2023; Umanah et al., 2022)

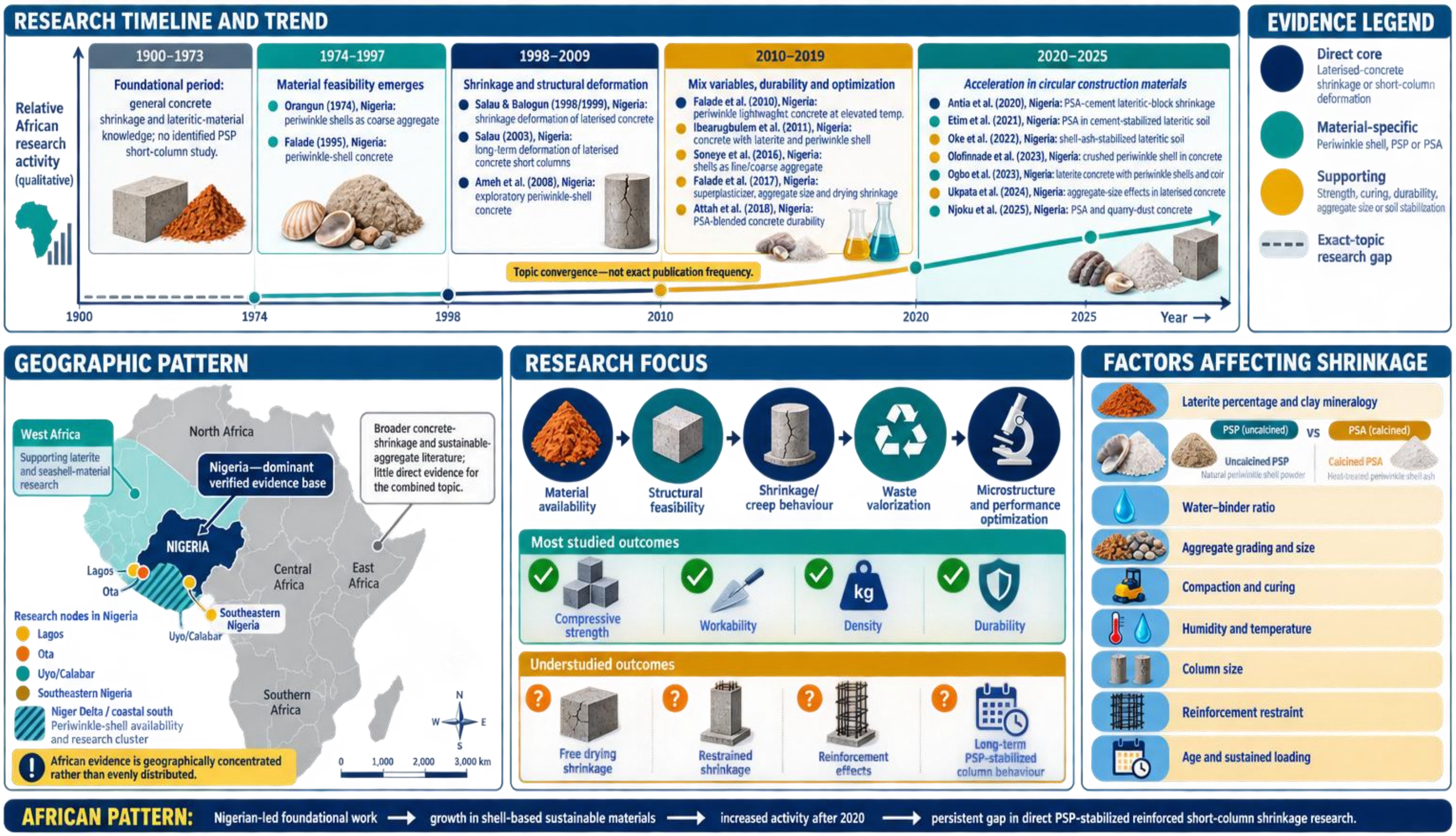

Figure 3b: Trend and Pattern of African Publications on factors affecting shrinkage of PSP -stabilized laterite concrete short column between 1900 and 2025

e. Laboratory Study and Results

Table 5 and Figure 4 present the effects of curing age, water–binder ratio (W/B), and simultaneous PSP–laterite replacement on the compressive strength and workability of the concrete mixtures. The compressive-strength unit was

The effects of the selected factors are presented as follows:

- **Compressive-strength development with curing age**: All mixtures generally gained strength as curing progressed from 7 to 28 days. This is consistent with continued cement hydration and gradual development of the hardened concrete matrix. The increase was most pronounced in the control mixtures.

W/B	Replacement	7-day mean	28-day mean	Increase
0.5	0%	5.17	16.47	218.6%
0.5	10%	4.20	9.00	114.3%
0.5	20%	3.13	5.43	73.5%
0.5	30%	2.47	5.20	110.5%
0.6	0%	6.43	18.67	190.4%
0.6	10%	8.43	13.00	54.2%
0.6	20%	5.33	11.00	106.4%
0.6	30%	3.80	7.13	87.6%

The discussions are as indicated

- For water-binder ratio of 0.5, the control strength increased sharply from 5.17 at 7 days to 12.00 at 14 days. It then increased more slowly to 12.67 at 21 days before reaching 16.47 at 28 days. The relatively small and quantity change between 14 and 21 days in the strength of the concrete suggests a temporary slowing of strength development, which was followed by further improvement between 21 and 28 days.
- At the same water-binder ratio, the 10% replacement mixture in the concrete increased from 4.20 to 9.00. The 20% mixture rose from 3.13 to 5.43, while the 30% mixture increased the strength from 2.47 to 5.20. This result indicates that every mixture benefited from longer curing; the replacement mixtures did not attain the strength of the control.
- For a water-binder ratio of 0.6, the control mixture increased in strength from 6.43 at 7 days to 12.00, 15.00, and 18.67 at 14, 21, and 28 days, respectively. This result represents the highest 28-day mean in the investigation. The 10% replacement mixture increased the strength from 8.43 to 13.00, while the corresponding results for the 20% and 30% mixtures increased from 5.33 to 11.00 and from 3.80 to 7.13, respectively.

From these results, the broadly progressive strength development indicates that hydration continued throughout the curing period. Possible delayed reactions involving the fine PSP and lateritic components may also have contributed to later-age strength; however, the results alone do not confirm a pozzolanic reaction. Mineralogical or chemical evidence would be needed to establish that mechanism.

Effect of PSP–laterite replacement level: Increasing the replacement level generally reduced compressive strength. This trend is particularly clear at 28 days, which can be discussed as follows:

- For a water-binder ratio of 0.5, the 28-day strengths were: 0% replacement: 16.47; 10% replacement: 9.00; 20% replacement: 5.43; and 30% replacement: 5.20. Relative to the control, the strength reductions were approximately 45.4%, 67.0%, and 68.4% at 10%, 20% and 30% replacement, respectively.
- For a water-binder ratio of 0.6, the corresponding 28-day strengths were: 0% replacement: 18.67; 10% replacement: 13.00; 20% replacement: 11.00; and 30% replacement: 7.13. These

represent reductions of approximately 30.4%, 41.1%, and 61.8% relative to the water-binder ratio of 0.6 control. The reduction probably reflects a dilution of the effective Portland-cement content as PSP replacement increased. If PSP had lower early-age reactivity than cement, less calcium-silicate-hydrate gel would initially be produced. Simultaneous laterite replacement of fine aggregate could also change particle packing, water demand, interfacial bonding, and pore structure. At high replacement levels, these effects may produce a more porous or less strongly bonded concrete matrix. The results nevertheless show that 10% replacement performed substantially better than 20% and 30% replacement. At 28 days and a water-binder ratio of 0.6, for example, the 10% mixture achieved 13.00, compared with 11.00 and 7.13 for the 20% and 30% mixtures. Consequently, 10% appears to be the most favourable of the investigated replacement levels where strength retention is the main criterion.

- **Influence of water–binder ratio:** Contrary to the conventional expectation that an increased W/B ratio eventually reduces concrete strength, the mixtures prepared at a water- binder ratio of 0.6 generally recorded higher strengths than their water- binder ratio of 0.5 counterparts. At 28 days, increasing W/B from 0.5 to 0.6 raised the mean strengths as follows:

Replacement	water-binder ratio of 0.5	water-binder ratio of 0.6	Difference
0%	16.47	18.67	+13.4%
10%	9.00	13.00	+44.4%
20%	5.43	11.00	+102.6%
30%	5.20	7.13	+37.1%

The greatest relative improvement occurred at 20% replacement. This suggests that a water-binder ratio of 0.5 might not have supplied adequate workable water for satisfactory mixing, placement and compaction of the PSP–laterite mixtures. Fine PSP and lateritic particles can increase surface area and water demand. Consequently, the mixtures at a water-binder ratio of 0.5 may have been relatively stiff, leading to incomplete compaction, entrapped air, and reduced strength of the concrete. The water-binder ratio of 0.6 mixtures was more workable and may therefore have developed better consolidation and fewer compaction voids. In this experiment, the benefit obtained from improved workability apparently outweighed the potentially adverse effect of adding more water. This does not mean that still higher water-binder ratios would continue to increase strength; beyond an optimum point, excess water would normally increase capillary porosity and reduce strength.

- **Slump and workability**: Figure 4 shows that slump increased with both replacement level and W/B ratio.

Replacement	Slump at water-binder ratio of 0.5	Slump at water-binder ratio of 0.6
0%	10 mm	20 mm
10%	16 mm	28 mm
20%	25 mm	33 mm
30%	30 mm	40 mm

At a water-binder ratio of 0.5, slump increased from 10 mm for the control to 30 mm at 30% replacement. At a water-binder ratio of 0.6, it increased from 20 to 40 mm. Raising the W/B (water-to-binder) ratio produced an 8–12 mm increase in slump, depending on the replacement level. The increasing slump suggests that the combined PSP–laterite replacement reduced the stiffness of the fresh mixture under the adopted batching conditions. This might have resulted from reduced cement content, changes in particle grading, smoother particle movement or less water being chemically bound at the time of testing. Nevertheless, absorption and particle-shape data are needed before a particular mechanism can be confirmed. All recorded slumps—10–40 mm—indicate relatively low workability or stiff concrete. The control mixture at a water-binder ratio of 0.5, with a slump of only 10 mm, would have required considerable compactive effort. The 30% mixture at a water-binder ratio of 0.6 was the most workable, although it recorded the lowest strength among the water-binder ratio of 0.6 mixtures. Thus, increased workability did not necessarily translate into increased strength when achieved by increasing the replacement level.

- **Relationship between slump and strength:** The figure reveals two different relationships as follows:
  - Increasing water-binder ratio from 0.5 to 0.6 increased both slump and measured strength; and
  - Increasing PSP–laterite replacement increased slump but generally reduced strength.

  These results indicate that slump was not a direct predictor of compressive strength. The higher water-to-binder ratio probably improved compaction sufficiently to enhance and increase the strength, whereas at higher replacement levels the process improved workability and simultaneously diluted or weakened the load-bearing cementitious matrix. This distinction or observation is important. The 30% mixtures produced the highest slump values between 30 and 40 mm, but relatively low 28-day strengths of 5.20 and 7.13. Conversely, the control mixtures had the lowest slump values but the highest strengths. Selection of a suitable mixture must therefore balance workability, compaction requirements and required structural strength. Variability among replicate specimens: Each reported mean was calculated from three specimens, and some individual results show noticeable variation as indicated:
  - The water-binder ratio of 0.5 control at 21 days ranged from 10.00 to 16.00.
  - The water-binder ratio of 0.6 control at 21 days ranged from 12.00 to 18.00.
  - The water-binder ratio of 0.5, 10% mixture at 28 days ranged from 6.00 to 11.00.
  - The water-binder ratio of 0.6, 10% mixture at 28 days ranged from 10.00 to 15.00.

These results of the relationship between slump and strength spreads may be due to variations in batching, compaction, curing, specimen dimensions, aggregate distribution, or testing alignment. In summary, it can be reported that the dominant findings are that Compressive strength generally increased with curing age, the control concrete recorded the highest later-age strength.
Increasing PSP–laterite replacement generally reduced strength; a water-binder ratio of 0.6 produced higher slump and, within the tested range, higher strength than the water-binder ratio of 0.5, Slump increased progressively with replacement level, and the 10% mixture gave the best strength retention among the replacement mixtures.

Table 5: Compressive strength Test of the short Column

W/B	PSP (%)	Laterite (%)	7 DAYS				14 DAYS				21 DAYS				28 DAYS				Slump (mm)
			1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	
0.5	0%	0%	5.00	4.50	6.00	5.17	11.00	12.00	13.00	12.00	16.00	12.00	10.00	12.67	16.00	16.00	17.40	16.47	10
0.6	0%	0%	6.40	6.50	6.40	6.43	13.50	11.00	11.50	12.00	12.00	18.00	15.00	15.00	15.00	20.00	21.00	18.67	20
0.5	10%	10%	4.60	3.00	5.00	4.20	6.80	5.00	4.00	5.27	5.00	10.00	11.00	8.67	6.00	11.00	10.00	9.00	16
0.6	10%	10%	9.00	8.80	7.50	8.43	12.00	10.00	11.00	11.00	12.00	11.00	12.00	11.67	15.00	10.00	14.00	13.00	28
0.5	20%	20%	3.00	3.60	2.80	3.13	3.60	3.60	3.00	3.40	5.50	4.00	4.60	4.70	4.80	5.50	6.00	5.43	25
0.6	20%	20%	5.00	6.00	5.00	5.33	5.00	6.00	9.00	6.67	11.00	9.00	12.00	10.67	10.00	12.00	11.00	11.00	33
0.5	30%	30%	2.40	2.00	3.00	2.47	2.60	4.00	3.40	3.33	4.60	5.00	4.00	4.53	6.00	4.00	5.60	5.20	30
0.6	30%	30%	4.20	4.00	3.20	3.80	3.80	4.40	3.40	3.87	8.00	7.00	6.00	7.00	6.80	8.00	6.60	7.13	40

Notes: Mean values were recalculated from the three specimen results. The compressive-strength unit was not supplied in the source table.

Key: Control mixes (0% replacement) Recalculated means

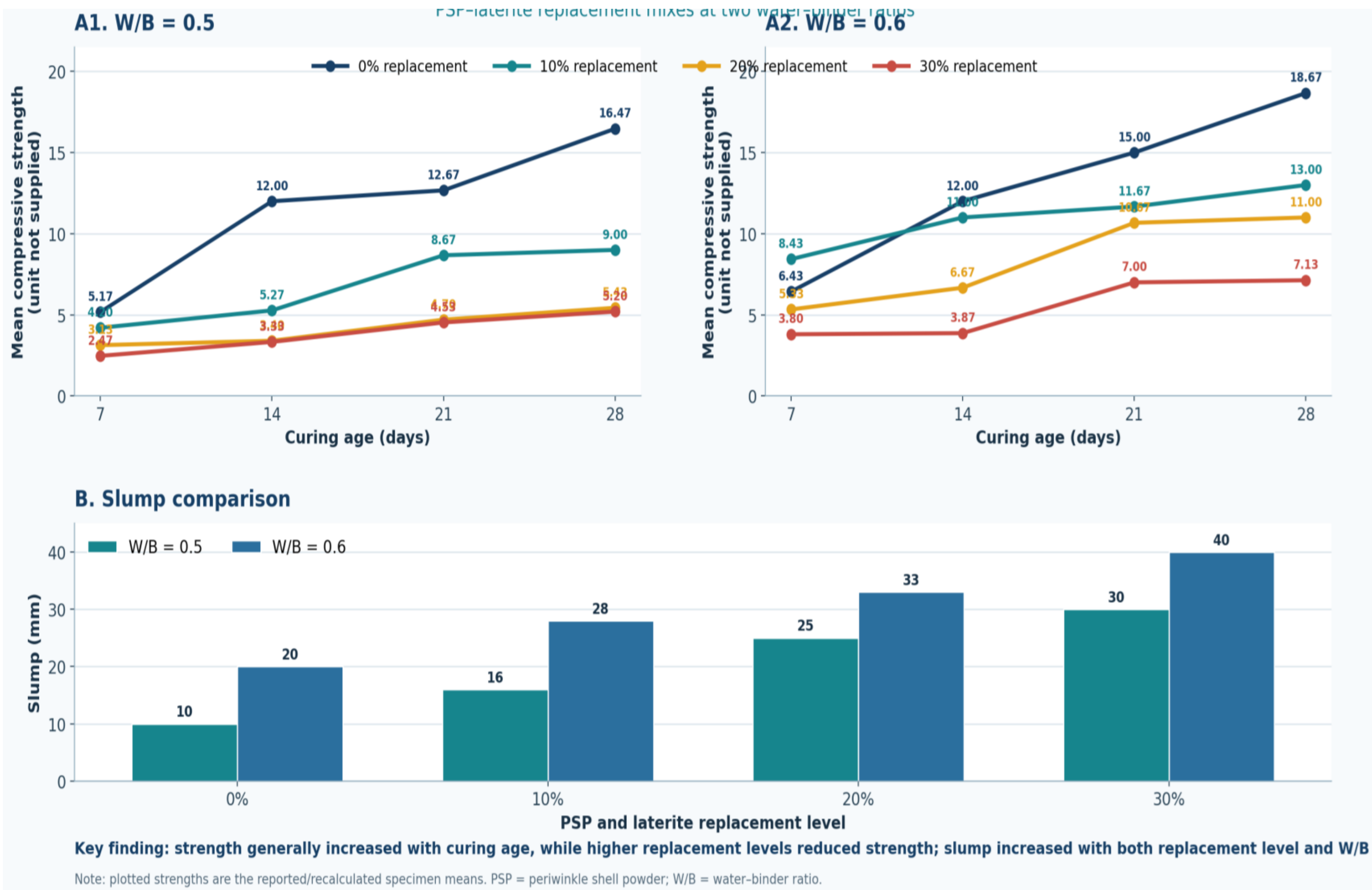

Figure 4: Compressive strength of short column and slump tests of the concrete

Table 6 and Figure 5 present the development of shrinkage deformation in PSP-stabilised laterised concrete short columns over 50 days. Four mixtures, which were investigated: the 0% control and mixtures containing 10%, 20%, and 30% PSP–laterite replacement. The results demonstrate two dominant effects: shrinkage increased with time, and increased substantially as the replacement level increased. The general shrinkage behaviour of these short columns can be summarised as follows:

- All four mixtures experienced progressive deformation during the observation period, and
- The curves rise rapidly during the early ages and then become flatter at later ages. This is typical of time-dependent shrinkage: a relatively large proportion develops initially when moisture loss and microstructural changes are greatest, while the subsequent rate decreases as the concrete approaches a more stable moisture condition. The final 50-day results were:

PSP–laterite replacement	Day 1 (mm)	Day 50 (mm)	Increase, days 1–50 (mm)	Relative to control at day 50
0%	0.00254	0.06858	0.06604	1.00
10%	0.02000	0.17000	0.15000	2.48
20%	0.01200	0.23900	0.22700	3.49
30%	0.02032	0.27000	0.24968	3.94

It can be surmised that at 50 days, the deformation increased from 0.06858 mm in the control to 0.17000, 0.23900 and 0.27000 mm in the 10%, 20% and 30% mixtures, respectively. Relative to the control, these correspond to increases equivalent to: 147.9% at 10% replacement; 248.5% at 20% replacement; and 293.7% at 30% replacement, which indicate that the 30% mixture recorded almost four times the shrinkage deformation of the control at 50 days. The shrinkage behaviour of the control mixture can be broken down as follows:

The 0% PSP–laterite control consistently recorded the lowest shrinkage. Its deformation increased from 0.00254 mm on day 1 to 0.01778 mm on day 13. A noticeable increase occurred between days 13 and 14, when deformation rose to 0.02794 mm. It then increased gradually to 0.06858 mm at day 50. The low deformation of the control suggests that conventional cement and aggregate produced a comparatively stable and well-bonded concrete matrix. The control mixture probably had a higher effective cement content and a denser internal structure than the replacement mixtures. A denser matrix would generally restrict moisture movement and reduce volumetric contraction. Approximately 40.7% of the control's final 50-day shrinkage had developed by day 14. Its shrinkage therefore continued more gradually through the later observation period than that of the replacement mixtures.

Behaviour of the 10% replacement mixture: The 10% mixture increased from 0.02000 mm on day 1 to 0.05000 mm on day 4 and 0.10000 mm by day 8. By day 14, its deformation had reached 0.13000 mm. It subsequently increased slowly to 0.17000 mm at day 50. This mixture displayed substantial early shrinkage but comparatively modest later-age growth. About 76.5% of its final deformation had already developed by day 14. Between days 14 and 50, shrinkage increased by only 0.04000 mm. Several nearly horizontal portions are evident in the curve. For example, the values remained at 0.13000 mm between days 12 and 14. Such intervals indicate either temporary stabilisation or changes smaller than the measuring system could resolve. They should not necessarily be interpreted as a complete cessation of shrinkage. Among the modified mixtures, the 10% replacement level produced the lowest final deformation. It therefore appears to provide the best dimensional stability of the three replacement mixtures.

- **Behaviour of the 20% replacement mixture:** The 20% mixture increased from 0.01200 mm on day 1 to 0.08000 mm by days 4–5. A relatively sharp increase occurred between days 5 and 6, when deformation rose from 0.08000 to 0.12800 mm. It then increased to 0.18400 mm at day 14 and 0.18800 mm at day 15. At day 21, its deformation was 0.19900 mm. This increased to 0.21000 mm at day 23 and then rose gradually to 0.23900 mm at day 50. Approximately 77.0% of its final 50-day deformation had developed by day 14. The 20% mixture recorded 0.06900 mm more deformation than the 10% mixture at day 50, representing an increase of approximately 40.6%. This result indicates that increasing the replacement level from 10% to 20% caused a marked loss of dimensional stability.

- Behaviour of the 30% replacement mixture: The 30% mixture generally exhibited the highest shrinkage throughout the observation period. Its deformation increased from 0.02032 mm on day 1 to 0.09620 mm on day 4, 0.15420 mm on day 7 and 0.20000 mm at day 14. Approximately 74.1% of its final shrinkage had therefore occurred by day 14. The value increased slightly to 0.21000 mm at day 21, followed by a pronounced rise to 0.24120 mm at day 23. Thereafter, shrinkage increased more slowly, reaching 0.27000 mm at day 50. The jump between days 21 and 23—0.03120 mm—is one of the most prominent changes in the dataset. A smaller increase was simultaneously recorded by the 20% mixture. This may reflect a change in the drying environment, moisture-loss rate or measurement condition. Because the increase occurs in more than one mixture, the laboratory records for this interval should be reviewed for changes in temperature, relative humidity, specimen exposure or measurement procedure. The 30% mixture recorded 0.03100 mm more final deformation than the 20% mixture, equivalent to an increase of approximately 13.0%. Although the difference between 20% and 30% was smaller than the difference between 10% and 20%, the 30% mixture remained the least dimensionally stable.

- **Early- and later-age development:** The study revealed that there is a large proportion of the final shrinkage developed within the first 14 days of curing, which can be presented as follows:

Percentage Replacement	Shrinkage in first 14 days (mm)	Shrinkage in the first 50 days (mm)	Percentage of shrinkage developed in the first 14 days compared to 50 days 14
0%	0.02794	0.06858	40.7%
10%	0.13000	0.17000	76.5%
20%	0.18400	0.23900	77.0%
30%	0.20000	0.27000	74.1%

From these results, it can be established that the replacement mixtures of the concrete developed three-quarters of their 50-day shrinkage by the first 14 days, but only about two-fifths of the control's final deformation or shrinkage had developed by that time. This indicates that PSP–laterite incorporation accelerated early deformation, even though shrinkage continued at a slower rate thereafter. From days 14 to 50, additional deformation amounted to: 0.04064 mm for the control; 0.04000 mm for the 10% mixture;
0.05500 mm for the 20% mixture; and 0.07000 mm for the 30% mixture. This result indicates that the 30% mixture exhibited both high early shrinkage and the greatest continued deformation after day 14.

- **Effect of replacement level:** The influence of replacement level is especially clear at the later observation ages. At day 50, the order was 30 % greater than 20 % greater than 10. This ordering indicates a strong positive relationship between PSP–laterite content and shrinkage deformation. Increasing the replacement level probably altered several characteristics of the concrete: effective cement content; paste-to-aggregate relationship; water demand and moisture retention; particle packing and internal porosity; stiffness of the solid skeleton; and quality of the paste–aggregate interfacial zone. This result indicates that replacing cement with PSP may reduce the quantity of conventional hydration products when the PSP is less reactive than Portland cement. Simultaneous replacement of conventional fine aggregate with laterite can introduce more fine particles and clay-sized material, which may increase water demand and drying sensitivity. A less rigid or more porous matrix offers reduced resistance to capillary contraction, resulting in greater shrinkage. The mechanism cannot be established from deformation measurements alone. Particle-size distribution, water absorption, oxide composition, mineralogy and microstructural analyses would help explain the observed response.

- **Relationship with the compressive-strength results:** When considered alongside Table 6 and Figure 5, an inverse relationship is apparent between shrinkage deformation and compressive strength. The control mixture recorded the highest compressive strength and the lowest shrinkage, while the 30% mixture generally recorded the lowest strength and highest shrinkage. This combined behaviour suggests that increasing PSP–laterite replacement produced a less rigid and possibly more porous concrete matrix. The weaker internal structure was less able to resist the tensile stresses caused by moisture loss and contraction. The 10% replacement level offered the most favourable compromise among the modified mixtures because it retained more compressive strength and developed less shrinkage than the 20% and 30% mixtures. The results revealed that compressive strength and shrinkage were apparently measured using different specimen forms and possibly different water–binder conditions. Their relationship should therefore be described as an observed association rather than direct proof of causation.

- **Engineering implications of all these relationships**: The results have important implications for the use of PSP–laterite concrete in columns and other restrained structural elements. Excessive shrinkage of any structure can produce: dimensional instability; surface and internal cracking; loss of serviceability; reduced durability; increased permeability; reinforcement exposure; and additional stresses where contraction is restrained. It can be highlighted that the recorded absolute length changes are small; their structural significance depends on the original gauge length of the columns. These results demonstrate that shrinkage deformation increased with both observation duration and PSP–laterite replacement level. The replacement mixtures developed most of their deformation during the first 14 days, followed by slower but continuing shrinkage. At 50 days, the control recorded the lowest deformation of 0.06858 mm, while the 30% mixture recorded the highest deformation of 0.27000 mm.

Table 6: Shrinkage deformation of the short column

OBSERVATIONS I

Duration (days)	0% PSP + laterite	10% PSP + laterite	20% PSP + laterite	30% PSP + laterite
1	0.00254	0.02000	0.01200	0.02032
2	0.00508	0.03100	0.03600	0.03800
3	0.00762	0.04500	0.05600	0.06410
4	0.00889	0.05000	0.08000	0.09620
5	0.00889	0.06430	0.08000	0.10200
6	0.01016	0.08240	0.12800	0.14100
7	0.01016	0.09000	0.13600	0.15420
8	0.01270	0.10000	0.13800	0.15660
9	0.01397	0.11500	0.14200	0.16870
10	0.01524	0.11600	0.15000	0.17200
11	0.01651	0.12200	0.16200	0.18000
12	0.01778	0.13000	0.17400	0.18600
13	0.01778	0.13000	0.17400	0.19500
14	0.02794	0.13000	0.18400	0.20000
15	0.03048	0.13600	0.18800	0.20200

OBSERVATIONS II

Duration (days)	0% PSP + laterite	10% PSP + laterite	20% PSP + laterite	30% PSP + laterite
17	0.03302	0.14200	0.19200	0.20510
18	0.03556	0.14300	0.19400	0.20700
19	0.03556	0.14400	0.19700	0.20910
21	0.03810	0.14800	0.19900	0.21000
23	0.03810	0.15200	0.21000	0.24120
25	0.04318	0.15400	0.21400	0.24310
27	0.04572	0.15500	0.21600	0.24500
29	0.04826	0.15600	0.22000	0.24810
32	0.05334	0.15900	0.22200	0.24990
38	0.05842	0.16300	0.22800	0.25400
41	0.06096	0.16500	0.23200	0.25720
44	0.06350	0.16600	0.23400	0.26040
47	0.06604	0.16800	0.23600	0.26600
50	0.06858	0.17000	0.23900	0.27000

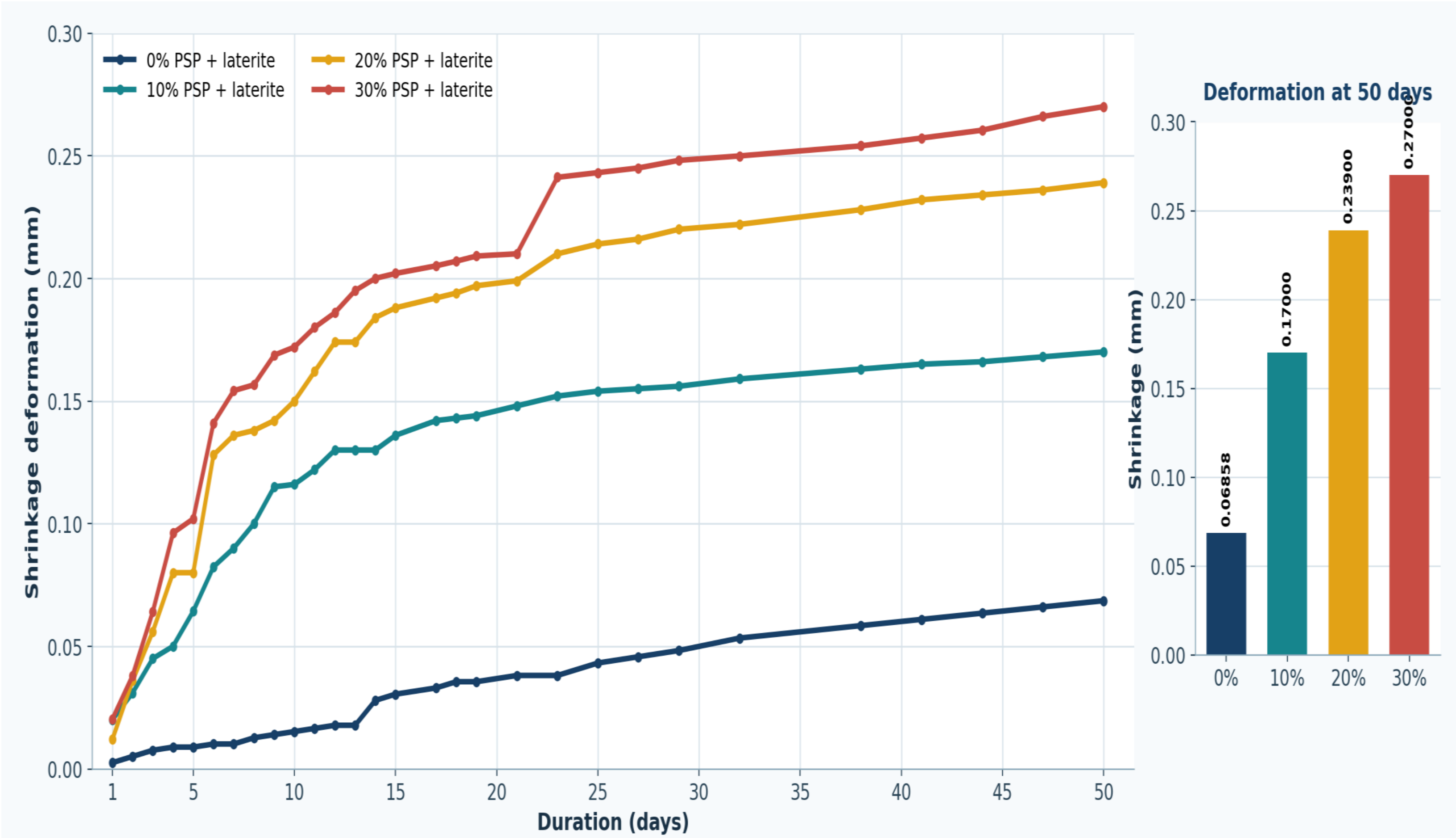

Figure 5: Shrinkage deformation of PSP- laterite Concrete

CONCLUSIONS

Based on the study, it can be concluded that:

- the slump increases with an increase in the percentage of periwinkle shell powder and lateritic soil
- as the slump increases, the workability also increases, and as the slump decreases, the workability also decreases.
- the use of periwinkle shell powder and lateritic soil as partial replacement of cement and sand in concrete can be done,
- that high PSP–laterite replacement levels adversely affected dimensional stability,
- the modified mixtures, the 10% replacement mixture performed best,
- whereas the 30% mixture was most susceptible to shrinkage.
- based on the combined strength and shrinkage results, a relatively low replacement level appears more suitable
- higher workability at 20–30% replacement did not compensate for the accompanying strength loss.
- In summary, the results suggest that a moderate replacement level—particularly 10% at water-binder ratio of 0.6 provides the most favourable balance between workability and compressive strength among the modified mixtures tested.

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