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The Future and Prospects of Periwinkle Composites in Reinforced Concretes: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Authors NA and OE co-designed the study, performed aninitial review, and wrote the first draft of the manuscript. Authors OG and OM handled the study literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The choice of building materials and the rising cost of construction materials have continued to plaque the building and construction industry without an immediate solution. Industrialists and scholars are investigating several naturally occurring materials for concrete composite reinforcements. The article chronologically reviewed the growth and development of periwinkle shell powder (PSP) and periwinkle ash powder (PSA) as composite materials in concretes. Findings showed that 28 days of curing age are required for lightweight concretes reinforced with PSP or PAP at 10-30% optimum. Produced lightweight concretes were susceptible to acidic medium and induce lower compressive strength which eventually leads to concrete/structure disintegrate and collapse. Research challenges and funding hamper the application of PSP/PAP in the concrete formulation and are unable to drive innovations and economic benefits as a composite. Advances in concrete technology showed that PSP/PSA mollusk shells achieve pillar strength grade and weight/load bearing status for the improvement of PSP/PSA blended concretes. Also, the composite potential showed that the functionalization of PSP/PSA, sustainability, and

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nano modification of cementitious materials and concretes are promising. Future studies are required to develop periwinkle reinforced concrete silos, sewers, and smart concrete materials with improved mechanical, thermal, and aesthetic properties.

Keywords: Concrete reinforcement; composite material; building materials; mollusk shells and sustainability.

1. INTRODUCTION

The thought-provoking choice of building and construction materials in the industry is challenging. The four major materials common in the industry includes steel, wood, masonry, and concrete. Interestingly, a number of these materials possess composite properties but are inadequate in stiffness, durability, and strength. The use of wood, for example, is vulnerable to moisture damage and decay, because it contains fibers and a lignin matrix [1]. Then again, the prices of steel keep soaring and its manufacturing consumes lots of energy, it is environmentally unfriendly (two tonnes of CO_2 are produced during the manufacture of one ton of steel) and there are calls to reduce its usage [2]. In the meantime, masonry is expensive, absorbs moisture, color deterioration, low tensile, and requires a heavy foundation [3]. On the other hand, concrete has high compressive strength, low tensile strength, and a high weight to strength ratio. Also, concrete is easily susceptible to pH and its production requires huge energy demand [4]. No doubt the use of advanced fiber-reinforced polymers (carbon, glass, and aramid) has shown great promise in the building and construction industry by reinforcing stiffness and strength. Additionally, they are anisotropic, which has allowed the production of remarkable designs and attractive shapes to meet complex engineering. However, fiber-reinforced concretes are generally expensive, heavier than non-fiber concretes, susceptible to corrosion, and risk of fiber balling during mixing [5]. These and more for plenty of reasons have created material research gaps in the building and construction industry that require the development/formulation of composite materials that are cheaper, readily available and solve these issues without compromising the functional properties of the composite.

On the other hand, the rising cost of building and construction materials has led to the application of naturallY occurring materials in concrete composite applications. Subsequent advantages derivable from them include ease of availability, cost-effectiveness, biodegradability, toughness, high stiffness to weight ratio, and lightweight advantage to synthetic materials [6,7]. These materials have also found wider applications in the construction industry such as in concrete, laterites, reinforced plastics, cement, steel-reinforced concrete, and composite wooden beams [8,9]. Likewise, by choosing an appropriate combination of reinforcement and matrix material, the building and construction industry can formulate concrete properties (mixtures) that fit exactly into the requirements for a particular structure and a particular purpose [10,11].

This approach without doubt has continued to drive and revamp research interest into naturally occurring materials that can form composite materials of suitable strength and stiffness combined with lightness [12,13]. Some of the common naturally occurring materials of plants and animal origin in construction and building applications include oil palm shells, sugar cane bagasse ash, bamboo shells, Jute, sisal, coir, kenaf, rice husk, coconut shell, coir husk, and animal horns [14–18]. But among them all, mollusk shells are maintaining some kind of sustained interest in building and construction as a composite material. Oftentimes, integration of these mollusk shells into composite materials like polymers, ceramics, concretes, and clays provides a distinguishable improvement in their mechanical properties, while offering them new applications in building and construction [19,20]. The mollusk shells are driving sustained interest as reinforcements and fillers in traditional building/construction materials, however, the nature, form, type, and treatment, (physical, chemical, or thermal) greatly influence their behavior and performance [21,22]. For instance, research has used shellfish as a good polypropylene bio-filler and enhanced elongation at break, yield strength, and tensile strength [23]. Similarly, another work fabricated a composite powder material using prawn shell powder and lapatoxy-SP 100 resins [24]. African land snails were also used as composites in epoxy polymers that improved the wear resistance, deformation, tensile modulus, and bending strength of the epoxy polymer [25]. Whereas banana rasps snail shells have been used as reinforcement material in metal matrix composites [26]. As a result, many studies continued to explore the possibility of using mollusk shells in construction material applications. These shell composite materials however are not without a few challenges. The physical process issues (waste aggregation, separation, preparation, renewability, and sustainability), and chemical process issues (dispersion, interaction, compatibility, weak binding forces between fiber and matrix, low quantum yield, water diffusion, and gas barrier) are challenging [27,28]. But comparably, synthetic fiber composites like organic fibers, carbon fibers, and glass fibers are non-biodegradable, prone to heat and thermal damage. Overall, there are more harmful ecological impacts and environmental health hazards associated with steel manufacturing, cement making, and masonry construction when compared with mollusk shell composites [18,22]. A notable mollusk shell among several emerging shells of biological litter is the Periwinkle Shell (PS). The Fig. 1 shows the various common animal shells that often cluster on the shores of the oceans as biological liter. The conch shell is similar to periwnkle shell by posses protuding spikes and regular sharp points unlike snail shells, egg shells that are round and smooth, while oyster shell is round and flat.

It consists of pristine metal oxides with a high surface area that enables the exploitation of their synergy effect [29]. Unlike some other shells like eggshells and snail shells, PS is befalling with salient attention and slow progress in its advancement as a material composite, fillers, and reinforcements [30,31]. Interestingly, while the cost of concrete composites like granite, gravel, and cement types are increasing without corresponding substitutes, the PS presents a great exploitable opportunity of utilizing local resources that are abundant, cheap, readily available, and environmentally friendly. The periwinkle shell powder (PSP) and periwinkle shell ash (PSA) have been described as emerging materials with enormous potential to support composites such as pH resistance, improves stiffness and strength, and weight to strength ratio [32,33]. Extensive research conducted on Search Engines concerning periwinkle shell application in concretes returned a handful of peer-reviewed articles. But a thorough examination of the articles disclosed that the past decade has rekindled interest in the application of PSP/PSA in concretes formulation. Moreover, the widespread knowledge gap is observable with great potentials. Subsequently, what then has hampered periwinkle shell/ash exploitation in concretes and cements? and how will a renewed research interest in PSP/PSA drive innovation and inventions in concretes and construction material composites? Therefore, this article reviewed for the first time, the chronological development of PSP and PSA as fillers and reinforcements in concretes; in a bid to understand its successes and failures. Additionally, solutions are proferred on the future sustainability, nano prospects, and the economic efficiency of PSP and PSA in concretes formulation.

Fig. 1. Differant sea shells (a) snail shell, (b) oyster shell, (c) periwinkle shell, (d) giant conch shell, (e) crustacean shell, (f) chicken egg shell

2. SHELL IN CONCRETES

One of the earliest research articles on periwinkle shells' suitability as coarse aggregate was done by Orangun [34]. The research utilized Portland cement and conical-shaped periwinkle shells ground to powder for enhanced surface area. The findings showed that the periwinkle shell is fit for structural concrete in a non-acidic environment but is also dependent on the strength of the shells. The work recommended the determination of shrinkage and creep properties of behavior in shear force and stress. Similar work was done in 1995 that evaluated the workability of various concrete (cement, sand, granite) and periwinkle shell ratio mixture. They concluded that PSP was a lightweight material aggregate that had workability decreased as the quantity of PSP increased [35]. The research recommended further study on the complete replacement of granite by PSP and curing days extended beyond 28 days. These two research works created the exploitation of PSP/PSA as an alternative eco-friendly composite material in concretes and replacement combination for gravel, granite, sand, and cement.

For more than a decade, the application of PSP/PSA in concrete was not forthcoming. This blank period coincided with a period of great interest in synthetic fillers and composites. However, over a decade later Adewuyi and Adegoke [36] prepared PSP as coarse aggregates in full and partial replacement of granite in concrete. The published data showed satisfactory compressive strength. Moreover, the workability and compressibility of concrete reduced as the amount of periwinkle shell increased. This, according to their observation was because a higher proportion of PSP created insufficient binding force. Interestingly, regardless of this shortfall, economical savings of 14-17 % using 35-42 % PSP were attained. The recommendation further created awareness of this composite material. Subsequently, the suitability of periwinkle shell (PWS) as a partial replacement for gravel and granite in concrete was evaluated. An investigation was made which showed that workability decreases as PWS increased, but attributed to the texture and shape of PSP [37]. Remarkably, since the uniformity coefficient of PSP was 1.14, it suffices the PSP as a suitable material for concrete works but is better used in cast-in-place structures for cost savings. In addition, the study concluded that PSA/granite concrete is better than PSP/gravel concrete.

In the same year, a study evaluated the development of a composite material using PSP, Portland cement, and sand [38]. A core finding was that 28 days hydration period (curing) yielded composites that meet recommended standard for lightweight concretes. Hence, classical support to ASTM-77 recommended minimum duration. Another study on PWS revealed that PWS was only suitable at 300 ^{o}C for lightweight concretes. Additionally, long 90-day curing age gave a bulk density of 1733 and 1821 kg/m^3 that increased with curing age [39]. On the other hand, studies on PWS as an alternative material to concrete composite development over laterite and sand were carried out [40]. Research findings showed that a good mix ratio by mass ratio of 0.65: 1 : 1.5: 0.565: 1.75 by mass of water: cement: laterite: periwinkle shell: river stone yielded concretes of 25.11 N/mm^2 compressive strength and way higher than normal.

By the following year, efforts were .made to evaluate the suitability of periwinkle shell ash (PSA) as a partial replacement for ordinary Portland cement (OPC). Their research findings showed that workability and compacting factor (0.84-0.95) increased as the percentage of PSA increased [41]. This contrary finding challenged results from PSP where workability and compacting factor decreased as PSP increased [36,37]. This relationship was attributed to the grinding of PSA into a fine powder. Moreover, detailed characterization of periwinkle ash powder (PSA) showed that it contains several metal oxides, properties desirous for composite, and that PSA contains materials similar to the chemical content of cement [42]. Another interesting observation was that as PSA contents increased, the compressive strength decreased for specific durations, but increased again at different successive days of curing. In addition, 28 curing days of 10% PSA is an adequate replacement for cement substitution in structural concrete. Moreover, tensile strength is reduced when PSA increased beyond 10%, while concrete becomes (stiff) less workable with increasing PSA content [36,42]. Remarkably, an interesting work [43] developed an alternate improvement by adding $MgSO_4$ and PWS as part of concrete composite material. Compressive strength of the new composite increased with increasing concentration of $MgSO_4$ ($MgSO_4$ attack increased with duration and concentration) and the optimum control mix was determined to be 10% PSA content replacement. This result agreed with their previous research work wherein 10% PSA content in concrete was adequate [42,43]. A further reinvestigation of partial replacement for granite in concrete using a periwinkle shell was carried out [44]. The results agreed with previous findings that characterized PSP and recommended the material as a suitable aggregate for concrete production [40,42]. However, a new formulation was developed through the combination of bamboo leaf ashes (BLA) varied with various proportions of PSA. Remarkably, their findings showed that 20% ternary blended cement replacement is optimum [45]. Nevertheless, compressive strength decreased as bamboo leave ash increased within each curing age when the PSA was kept at 10%.

Similarly, the compressive strength increased when PSA varied from 0 to 30 % and BLA kept constant. Also, a blend of BLA at 15% with 10% PSA was recommended for normal non-load bearing concrete when the desired curing duration is a minimum of 28 days. Another research finding accessed the mechanical properties of BLA and PSA composites in concrete. A significant finding was that the blends containing 80% cement, 10% PAP and 10% BLA outperformed the standard reference mix at 28 and 56 days [46].

As the exploration of periwinkle shell continues to grow, researchers sought organic and inorganic supports to enhance concrete composites that contain PWS. Researchers now examined the effect of sodium nitrate as an accelerator in PSA blended with cement concrete [47]. Optimum concrete blend performance was achieved when PSP was 30% content and only 2% of $NaNO_3$. This confirmed that $NaNO_3$ can enhance the compressive strength and splitting strength performances of concretes. Similarly, the investigation was conducted on mechanical properties and crystal structure of concrete using different organic waste products including periwinkle shell, silica extracted from corn hub, and coconut shell [48]. Their findings showed that periwinkle and silica-reinforced concrete produces high-strength concretes. Interestingly, comparing the EDX and XRF instrumental characterization of cement and periwinkle shell revealed a high level of similarity in their chemical content, but different mechanical behavior. However, the study did not examine binary composites or hybrid composites in concrete admixtures, though, it is challenging to find the optimal replacement ratio of binary and hybrid composites in concrete blends or admixtures. Scientists further investigated this matter to determine a solution to multi-composites in concretes using the palm kernel shell (PKS) and PSA. The materials enhanced concrete behavior using the PKS and PSA in rather asphaltic concrete. Furthermore, with 36 samples prepared from 0-50% (PKS and PSA) replacement for coarse aggregates, it was observed that 10 or 20% partial replacements of PSP and PSA produced light road traffic alternatives [48,49]. This finding also correlated with the previous findings from published works [45,46].

On the other hand, authors reassessed periwinkle shell feasibility as partial replacements for coarse aggregates, and PSA as a fine and coarse aggregate in concretes. The studies confirmed that PSA can be used when lightweight structural concrete is desired. Moreover, 30% replacement of sharp sand by PSA was a satisfactory mixture ratio for low-cost/lightweight buildings as well as 6.8% cost-savings [50,51]. The results also agreed with the research findings of several previous publications [34,40,47]. Moreover, the cost savings were low compared to an earlier finding that made savings of 14-17% using 35-42% PSA [36]. Research incorporating $MgSO_{4(s)}$ together with PSA and HCl(aq) which examined the composite concrete behavior under harsh conditions was carried out by Oke et al., [52]. The compressive strength decreased as PSA% composition increased contrary to other study findings [43]. The behavior is owing to the high concentrations of $HCl_{(aq)}$ and the use of PSA calcined at 1000^oC. Comparably, however, both results proved that 10% replacement of cement with PSA showed the optimum performance. In addition, concrete containing $MgSO_4$ performed better under acid attack than mixtures containing PSA. Likewise, their findings established that 28 days of curing age, significantly affects the compressive strengths of concrete containing PSA similar to previous reports [40].

Modeling the flexural strength of sandstone and periwinkle reinforced concrete to predict the relationship with curing days was performed. Using regression modeling and Fisher's statistical tool, the calculated fisher value of 2.13 was less than the statistical fisher value of 2.48 from the f-distribution table [53]. Hence, there was no significant difference (5% level) between the laboratory flexural strength value and the model flexural strength values. Secondly, their discovery effectively reduced the time for carrying out trial mixes for the desired fresh or hardened concrete properties. Lastly, their research findings further established that 28 days of curing age is recommended for lightweight concretes reinforced with PSP or PSA [38,52]. Furthermore, an assessment was taken to determine the compressive strength of PSA-blended cement concrete soaked in crude oil polluted water [54]. The findings showed that compressive strength increased with decreasing PSA replacement and increased with the age of curing of PSA replacement mixtures. Hence, the aggressive medium caused deterioration and loss in compressive strength. Researchers also worked on the permeability and sorptivity of PSP and recommended that PSP can be incorporated into structures like bridges and dams [55]. Also, the authors recommended PSA mixtures of 40% for low-strength concrete in the absence of compressive strength analysis. However, the recommended the need to investigate the nature of alkaline or acidic medium that affects PSA composites in concretes.

Thus, the critical mix ratio of concretes, asphaltic, or laterite blends with PSA/PSP that can withstand acidic and alkaline environments has remained vague and unclear. An alternative study conducted on the optimization of PSP strength as a concrete aggregate was performed [56]. The experimental data agreed with the regression model using a 1:3:6 mix ratio and the maximum strength was 19.50 N/mm^2. The findings proposed its application for predicting and optimizing other structural properties [53]. On the other hand, experimental investigations confirmed that PKS and PWS are rather good partial replacements in asphaltic and non-asphaltic lightweight concrete when combined [57]. Likewise, a new study investigated the replacement of granite by PSA and rice husk ash (RHA) in concretes using different mixing ratios [58]. They found that a smaller quantity of super-plasticizer agents was needed to facilitate high water reduction. Also, compressive strength had a value of 12.37 N/mm^2 for 1:1: 1 mix when the ratio of PSA was 80% and 20% RHA, hence the results showed that compressive strength and bulk density increased with PSA content and can be used in lightweight concrete.

Authors [59] investigated PSA performance when incorporated into asphaltic concrete; and found the optimum percentage as 6.1% bitumen and 20% PSA. Then again, another study investigated PSP as a partial replacement for cement in concretes [60]. The obtained results confirmed the findings from previous authors that 28 days compressive strength was optimum for partial replacements [36,46,50]. Interestingly, the characterized PSA had a chemical percentage composition of SiO_2, Al_2O_3, and Fe_2O_3 to be 33.85, 10.84, and 6.25 percentage which met the requirement of ASTMC 618-2008 for class C pozzolana with a value of 50.34% [60]. Notwithstanding, rice husk ash (RHA) and PSA (20%) were incorporated as coarse aggregate in concretes. Researchers proffer a solution for concretes requiring long transport and delayed setting times in varying proportions of 1:2:4 mixes [61], and similarly observed in bamboo leave ash [45]. Furthermore, an assessment of the suitability of fine and coarse aggregate replacement of concrete by PKS and PSP was carried out [62].

The research findings showed that compressive strength of concrete with partial or full replacement of fine and coarse aggregates of PKS and PSP, has an inverse relationship with the quantity of PKS and PSP added. This observation has been similarly reported [45,54]. A study evaluated PSA blended with cement and its behavior in the sulphuric acid environment. The findings posited that PSA did not mitigate the attacking behavior of sulphuric acid at 5- 10% concentration for 28 days [63]. Hence the findings were in agreement with other previous works [43,52]. From this review study, we construe that concentrated sulphuric acid medium presents an acid-base kind of interaction with the metal oxides in PSA to produce soluble metal salts. These soluble salts then become susceptible to acidic medium and induce lower compressive strength which eventually leads to concrete/structure collapse. A typical equation demonstrating the formation of soluble metal salts from the five major elements in PSA is proposed in the equations (1-5) below. It is observed that other oxides form soluble salts, while only SiO_2 is insoluble in H_2SO_4 at such moderate concentrations.

$$CaO_{(s)} + H_2SO_{4(aq)} \rightarrow CaSO_4 + H_2O \quad (1)$$

$$Fe_2O_{3(s)} + 3H_2SO_{4(aq)} \rightarrow Fe_2(SO_4)_3 + 3H_2O \quad (2)$$

$$Al_2O_{3(s)} + H_2SO_{4(aq)} \rightarrow Al_2(SO4)_3 + H_2O \quad (3)$$

$$SiO_{2(s)} + 2H_2SO_{4(aq)} \rightarrow SiO_2 + 2SO_3 + 2H_2O \quad (4)$$

$$MgO_{(s)} + H_2SO_{4(aq)} \rightarrow MgSO_4 + H_2O \quad (5)$$

John and ukpaka [64] blended clay soil ash and PSA into cement production to understand factors that affect compressibility during formulation. Interestingly, their findings showed that PSA was a good cement material. Also, the compressive strength when utilized in cement is comparable to common Nigerian cement. Furthermore, [65] investigated the potential of obtaining nanoparticles from periwinkle shells and other biowaste shells via the ball milling process. The study revealed that after 74:00 hr at 10 charge ratios for carbonized and uncarbonized periwinkle shell, it yielded nanoparticles of 49.23 and 56.53 nm respectively. Unfortunately, the impact of this successful research was not widely reported, and so was the future of PSP and PSA as nanoparticle composites unconventionally investigated to date. Thus, nanoparticles psp/pap remains an unexplored aspect of PSP and PSA in the formulation of reinforced concrete composites.

Modeling of a pulverized periwinkle shell and other bio-shells as pozzolana in concrete was performed to access their suitability as reinforced concrete composites [66]. The research model agreed with the obtained experimental results and the periwinkle shell was found to be a good retardant to setting time and workability. In addition, 10% replacement was suitable for structural works (28 curing days), however, increasing PSP percentage decreased compressive and tensile strength. The findings agreed with previous results on work carried out using PSP as a coarse aggregate [35,36,42]. Furthermore, the effect of sisal fiber blended into periwinkle shell ash cement composite was studied as a partial replacement of cement. The research showed that maximum compressive strength (28.8 n/mm^2) was achieved in 28 days of curing age while regular is 34.5 n/mm2. However, 5% PSA replacement for sisal fiber reinforced concrete was the optimal value without a successive decrease in compressive strength [67]. Then again, studies were conducted to ascertain the best curing methods during the formulation of periwinkle shell concretes using response surface methodology (68). Interestingly, the linear model predicted the compressive strength of the blended concrete for both water and air-cured blended concretes. Moreover, the compressive strength of water-cured PSP-blended concretes outperformed air-cured PSP-blended concrete. The optimum strength was achieved using a 10% periwinkle shell and 28 days curing duration. The findings also agreed with works done by previous authors and their findings [38,42,44].

Recently, a new investigation evaluated the effect of periwinkle shells on lateritic block water absorption and shrinkage [69]. As the amount of PSA replacement increased, shrinkage increased and water absorption increased. In addition, beyond 30% replacement, maximum block crack exceeded the allowable crack limit. Another interesting and recent work [70] evaluated abrasive lateritic block and the effects of PSA blended cement. The findings comparably showed that while 30% replacement on 28 days was suitable for non-load bearing walls, while 10-20% replacement was suitable for load-bearing walls akin to earlier work [37]. Furthermore, a research study reported that PSP (aggregate) reinforced concrete can be used as a layer in concrete beams requiring compression and a tension zone of about 0.5 h [71]. Lastly, a current study evaluated the compressive strength of lightweight concretes using PSP and PKS [72]. The findings corresponded with other research studies where density and strength increased with curing age for both aggregates [39,41,44,57].

3. REVIEW METHODOLOGY

In the offshore drilling operation, a subsea blowout preventer is placed on the seabed; and In summary, the key details of the reviewed articles using PSP and PSA as a fine or coarse aggregate in concretes and laterite were evaluated. The experimental findings are detailed in Table 1 and discussed further. The analysis confirmed that Nigeria is a leading producer and consumer of periwinkle membranes, shells, and ash. More significant is that 70% of obtained periwinkle shells were from the Nigeria Niger-delta regions whose environment is characterized by mangrove forests, salt, and brackish water, and muddy swamps. The conventional mix ratio ranged from 1:1:2, 1:2:3, 1:2:4, and 1:3:6 as reported by most authors. However, no study was conducted to determine the effect of mix ratio for specific composites when substituted with PSA (increase or decrease in weight percentage). Moreover, several authors evaluated 100% replacement for a particular concrete mix ratio. Their study developed lightweight concretes and not load-bearing concretes owing to their low compressive strength. On the other hand, no study was conducted on the application of PSP and PSA in the development of other building and construction applications like roofing, silos, and sewers. An overview of materials been applied in concrete/laterite development includes $NaNO_3$, $MgSO_4$, BLA, PKS, RHA in search of compatibility with PSP and PAP. Successful resistance to acid attack [43], long transport, and delayed setting times [61], were accomplished. Furthermore, partial replacements in asphaltic and non-asphaltic lightweight concrete were realized [57], and finally, light road traffic alternatives [49], was attained.

Although research findings confirmed that $NaNO_3$ can improve the compressive strength and splitting strength performances of concretes [47], nevertheless it was sufficient to be classified as a load-bearing concrete. Hence, advances in concrete developments to achieve pillar strength status and weight/load bearing status are required for the improvement of PSP and PSA blended concretes.

Interestingly, different sizes of shells, ash, and sieve were used by researchers. It becomes obvious to express that during experimental preparations, authors took different approaches to preparation and sieving. Some researchers calcined and crushed their periwinkle shell, a few others first crushed and calcined, some others only crushed to powder and the rest crushed it into smaller bits. Calcination temperature ranged from 600-1000^{o}C, but some authors reported 800^{o}C or 1000^{o}C as optimum calcination temperature [60], Sieve sizes ranged from 45-200 µm, while shell size/ash size was 4.75-60.0 mm, indicating variations in sizes of PSP/PSA. Hence, research is required in this area to study the effect of nano-size particles of PSP/PSA in concrete and laterite formulation and the compatibility with composites materials (BLA, RHA, and PKS) [65].

The range of bulk density was observed to be 1057-3210 kg/m^3. Also, improvements were obtained for lightweight concretes in combination with PSP/PSA [50,51]. However, research studies were not conducted in the aspect of PSP/PAP application in compressed concrete and characterization. Additionally, the average concrete bulk density is about 2400 kg/m^3, hence research needs to be carried over how much air is trapped in the concrete by taking cement concentration, sizes of fine or coarse aggregates, amount, and density of each composite into consideration. Unfortunately, many of the studies investigated the transformation of regular concretes to lightweight concretes using PSP/PSA. Consequently, the workability, appearance, bulk density, tensile strength, and compressive strength have all been reported for lightweight concretes. Therefore, more work needs to be done on the improvement of regular concretes reinforced with PSP/PSA to achieving structural concretes or compressed concretes status. A comparsion of the mechanical properties with some common building materials (Table 2) suggests that the bulk density of PSP/PSA reinforced concretes is comparable to Aluminum 303 and titanum. Hence, oppurtunities exist for improvement of PSP/PSA in the development of composites.

4. FINDINGS AND DISCUSSIONS

The potential prospects of PSP and PSA are represented diagrammatically (Fig. 2). It describes the six possible routes for periwinkle applications in material composites in concrete building and construction. At the initial stage (phase one), it shows that sustainable management starts with applying sustainability into the rearing of periwinkles for its membrane and shells. All environmental and human factors that favor its cultivation and harvesting in such a way that it is recycled renewable resources should be factored into consideration. During the second phase, the periwinkle shell had been obtained after the consumption of the membrane. The engineering and scientific application will determine if the shell will be prepared as a periwinkle shell powder (PSP) or as a periwinkle ash powder (PSA) and even as a nanoparticle. In addition, the functionalization of PSP/PSA has the potential to add new mechanical, chemical, material, and rheological properties into the composite concrete and cement that are used for building and construction. In summary, the economics of PSP/PSA in terms of cost reduction, economic efficiency, accessibility, availability, and environmental friendliness must be factored in at each stage. More of these dynamics of functionalization, nanoparticle application, green sustainability, and economics are discussed in detail.

4.1 Functionalization

Taking the properties of periwinkle shells (PSP/PSA) into consideration, it is suggested that cement and concrete bulk properties can be functionalized during cement formulation and concrete production. Functionalization is the process that adds new properties, features, functions, and capabilities to already existing conventional materials by changing the mechanical, thermal, and optical properties of the material. More especially, mechanical defects are common in concretes and can be improved by surface chemistry functionalization. There are several types of cement for different construction purposes that can be functionalized, and each of them differs in its chemical compositions. Ordinary Portland cement (OPC) is the most common among them; others include colored cement (CC), low-heat cement (LHC), hydrophobic cement (HpC), rapid hardening cement (RHC) and pozzolanic cement (PzC), and blast furnace slag cement (BFSC) [73]. The functionalization of cement types and concrete composite materials can act as a catalyst in the cement hydration reactions, inhibit premature failure in concretes, withstand large external forces during explosions and earthquakes, and add aesthetic value. It is also possible to produce crack-free concretes by incorporating nano PSP/PSA particles on a strong interfacial transition zone between cement paste and aggregates.

The prospects of functionalization of PSP/PSA in cement and concretes are promising. It is expected that this material will advance the performance of concrete and cement in the future. This will be achieved by successful incorporation into the development of sustainable, novel, advanced cement-based composites, and smart concrete materials with unique mechanical and thermal, and aesthetic properties. Such concretes include precast concretes, decorative concretes, translucent concretes, smart concretes and polymer concretes. Generally, they are treated in different ways to increase their aesthetic appeal, while maintaining their durability and mechanical properties. Typical treatments include decorative toppings, coloring, embedding items, texturing, molding, embossing, polishing, and etching. Therefore, the incorporation of PSP/PSA materials due to their high surface area to volume ratio can allow efficient functionalization in concretes to suit specific-oriented needs [73,74].

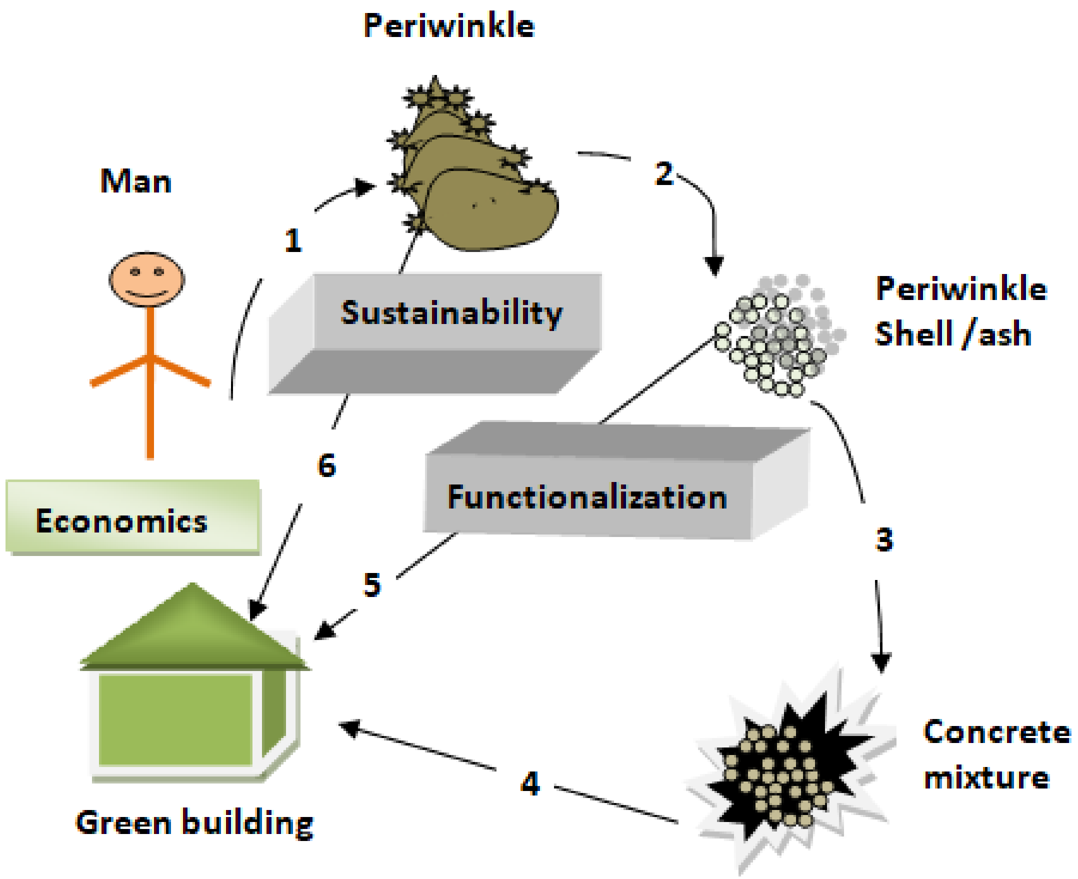

Fig. 2. dynamics of periwinkle shell/ash sustainability in concrete

Table 1. Characterization of periwnkle reinforced concretes

Periwinkle source	Mix ratio/ % replacement	Composite materials	Shell Size/ Sieve size	Bulk density (kg/m^3)	Compressive strength (N/mm^2)	Curing days	Ref
Nigeria	1:2:4; 1:1:2, 1:1$\frac{1}{2}$:3	Cement/sand/gravel/PWS	½" sieve	1762-2002	2.75-15.16	28	34
Nigeria	1:1$\frac{1}{2}$:3, 1:2.4, 1:3:6 1:3$\frac{1}{2}$:1, 1:4$\frac{1}{2}$:1	Cement/Sand/granite/PWS or PKS	20-60 mm shell	1700-2631	4.44 -21.56	28	35
Nigeria	1:2:4; 1:3:6 0-100% replacement	Cement/granite/Sand//PWS	3.23 mm shell	1481-1728	12.00-22.00	28	36
Nigeria	1:1:5:3	Cement/gravel/granite/Sand/PWS	9.52-12.70 mm shell	1944-2508	13.05-16.30	28	37
Unknown	1:2:3, 1:4:6, 1:2:4, 1:3:5	Cement/sand/PWS	3.35-15.00 mm shell	1979-2160	19.50-25.67	28	38
Unknown	1:2:2;1:2$\frac{1}{2}$:2	Cement/gravel/sand/PWS	6.30-25.0 mm shell	1427-1821	2.60 - 7.34	90	39
Nigeria	0.65:1:1.5:2.315 0.6: 1:1: 2.645.	Cement/laterite/river stone/PWS	ND	2090-2590	10.63-27.00	28	40
Nigeria	1:2:4 mix ration 0-20 % replacement	Cement/granite/sand/PWS	75 µm sieve size	2403-2978	9.74-22.22	28	41
Nigeria	0-40 % replacement	Cement/sand/stone/PWS	45 µm sieve size	NM	15.91-30.15	180	42
Nigeria	0-40 % replacement	Cement/MgSO4/PWS	45 µm sieve size	Sl. Ts 25-29	17.33-30.15	152	43
Nigeria	1:11$\frac{1}{2}$:3, 1:2:3, 1:2$\frac{1}{2}$:3 25-75 % replacement	Cement/granite/sand/PWS	ND	1956-3585	17.78-40.89	28	44
Nigeria	1:2:4 0-30 % replacement	Cement/granite/sand/ PSA or BLA	Calcined & crushed (15.00 mm shell)	2100-2500	10.38-25.50	56	45
Nigeria	1:2:4 5- 30 % replacement	Cement/sand/PSA/BLA	Calcined & crushed	Sp. St 1.10-2.44	10.60-23.43	56	46
Nigeria	0-40% replacement	Cement/$MgSO_4$/PWS	45 µm sieve size	Sl. Ts 25-29	17.63-30.15	152	47
Nigeria	0-30 % replacement	Cement/sand/granite/PSA/$NaNO_3$	75 µm sieve size	Sp. St 1.2-2.9	14.60-25.10	28	47
Unknown	10 % replacement	Cement/sand/granite/PWS/CHA/CS	150 µm shell	NM	213.99-217.94	5	48
Nigeria	0- 50 % replacement	Cement/bitumen/filler/PWS or PKS	5-15 mm shell	Fl. V 8-9 mm	M.St 2-3.2 KN	NA	49
Nigeria	0-50 % replacement	Cement/granite/Sand/PWS	12.5 mm shell	NM	10.0-22.0	28	50

Periwinkle source	Mix ratio/ % replacement	Composite materials	Shell Size/ Sieve size	Bulk density (kg/m^3)	Compressive strength (N/mm^2)	Curing days	Ref
Nigeria	1:2:4 0-20 % replacement	Cement/granite/sand/$MgSO_4$/HCl/ PWS	75 µm sieve size	NM	10.89-20.67	56	52
Nigeria	0-100 % replacement	Cement/granite/Sand/PWS	Crushed & uncrushed	NM	3.00-25.00	56	51
Nigeria	1:1 arbitrary	Cement/Sand/sand stone/PWS	1-19 mm shell	NM	Fl. St. 2.49-3.54	28	53
Nigeria	1:1:2, 1:2:4 0-40% replacement	Cement/granite/sand/PWS	45 µm sieve size	NM	9.00-29.3	28	60
Nigeria	1:3:6	Cement/ and/periwinkle	31.8-63.96. mm	NA	19.50	28	56
NM	5.0-7.0 % replacement	Asphalt/sand/bitumen/PWS	NM	2240-2440	M. Fl. 3.9 mm	NA	59
Nigeria	1:2:4	Cement/granite/sand/PKS/PWS	4.75 mm sieve	1820-1936	10.59-16.90	28	57
Nigeria	1:2:4 0- 20 % replacement	Cement/sand/crude oil/PWS	BS no 200 sieve size	Sl. Ts 21-29	14.00-25.00	28	54
Nigeria	0-40% replacement	Cement/quartzite/granite//PWS	75 µm sieve size	1057	NM	90	55
Nigeria	1:2:4 0-100% replacement	Cement/sand/granite/RHA/PWS	6.30-25 mm shell	Sl. Ts 13-23	Wa. Ab 0.2-1.5	28	56
Nigeria	$1:2:1\frac{1}{2}$, $1:1:1\frac{1}{2}$ 0-100% replacement	Cement/granite/sand/PWS/RHA	ND	1198-1848	6.80-16.36	35	58
Nigeria	1:2:4 0-100% replacement	Cement/Granite/mineral filler/sand//RHA/PWS	6.30-25 mm shell	Sp. St. 2.00-2.40	2.00-30.0	90	61
Nigeria	1:2:4 0-100 % replacement	Cement/PKS/PWS	19 mm sieve size	1410-2560	2.70-20.00	28	62
Nigeria	1:2:4 0-20 % replacement	Cement/sand/granite/PSA	BS no 200 sieve size	Sl. Ts 21-29	15.0-28.0	28	63
Nigeria	1:2:4, 1:3:6	Cement/Clay soil ash/PWS	7.5 µm sieve size	NM	10.0-15.0	21	64
Nigeria	1:2:4 0-50 % replacement	Cement/sand/granite/CS/PWS/PK S	90 µm sieve size	2300-2500	5.21-20.85	28	66
Nigeria	1:2:3 0-30 % replacement	Cement/granite/sand/PWS/SF	200 µm sieve size	Sl. Ts 0-30	14.0 -28.8	28	67
Unknown	0-15% replacement	Cement/sand/PWS	ND	NM	18.0-34.8	28	68
Unknown	0-50 % replacement	Cement/laterite soil/PSA	ND	1690-1890	1.01-4.80	28	69

Periwinkle source	Mix ratio/ % replacement	Composite materials	Shell Size/ Sieve size	Bulk density (kg/m^3)	Compressive strength (N/mm^2)	Curing days	Ref
Unknown	0-50 % replacement	Cement/lateritic soil/PSA	ND	3000-3210	Wa Ab.12-26.7 %	28	70
Nigeria	1:2:1, 1:2:4	Cement/sand/stones/PWS	ND	Cr.Ca (kNm) 3.22-5.37	9.18-28.60	28	71
Nigeria	1:2:4, 1:4:4, 1:2$\frac{1}{2}$:4	Cement/sand/PWS/PKS	4.75-16 mm shell	1410-1780	3.03-12.07	28	74

Table 2. Common building materials and their properties

Types of Materials	Tensile strength (PSI)	Yield strength (PSI)	Hardness Rockwell (B-scale)	Density (Kg/m^3)
Aluminum 3003	22,000	21,000	23	2730
Stainless steel 304	90,000	40,000	88	8000
Yellow brass	200,000	40,000	55	8470
Copper	20.000	28,000	10	8940
Titanium	62,000	37000	80	4500

4.2 Nano Particle

The incorporation of nanoparticles in concretes and cement mixtures is to large extent a welcomed development as it continues to proffer solutions to the modern cement and concrete industry. In essence, the addition of nanoparticles causes nano modification of cementitious materials and ensuring higher durability, decreasing transport loading and volume instability. Nano PSP and PAP are obtained by calcification and crushing to powder, sieving to different fractions, further crushing of intermediate size fractions, and lastly milling again to obtain sizes in the nano-range. For instance, research showed that concrete mixtures containing SiO2 and TiO2 nanoparticles can reduce cement inorganic content allowing chemically smoother and physically homogenous structures. Another researcher also incorporated Fe2O3 nanoparticles in concretes and observed that higher compressive strength achieved was comparable to concretes without nano-Fe_2O_3 particles [75]. Research showed that concretes modified with nano RHA-fly ash gave better results than fly ash concretes and concluded that nano-particles improve the structure of the aggregates' contact zone, resulting in a better bond between aggregates and cement paste [76]. Furthermore, the presence of 0.5% Al_2O_3 partial replacement for cement was reported to reduce sorptivity and increase the compressive strength of concrete up to 10% at 28 days. Whereas, the addition of nano $CaCO_3$ and SiO_2 as partial replacement of cement increased the durability and mechanical properties of the concrete [77]. Interestingly, PSP and PSA usually consist of 50-70 % Al_2O_3, $CaCO_3$, SiO_2, and Fe_2O_3. Thus, when milled into nanoparticles, they have a large surface area to volume ratio than their bulk counterparts. Due to this nano-size, they can fill up small cavities of the cement matrix and concrete mixtures, densifying the structures. The resultant effect improves strength and faster hydration reactions associated with cement and concretes. Therefore, the prospects of improving concrete via nano PSP and PSA should be explored to find suitable substitutes for cement and concretes [78–80].

4.3 Green Sustainability

Periwinkle is one of the edible membranes consumed by man, with more than 100million tonnes of shell disposed of globally per annum. It is reported that 5-8 % of the overall worldwide CO2 production emanates from the cement production industry. Notwithstanding, the advancement in cement and concretes has managed to be well-positioned as a building and construction material, whose life cycle and sustainability remain challenging. But with the advances in reinforced concretes with PSP/PSA, the overall outlook and prospects of this functional material are interesting and beneficial to the building and construction industry. The material (PSP and PSA) when used as cement and concrete composites can improve concrete quality, drive sustainable improvements, cost reductions, reduction of greenhouse emissions, and energy savings.

Given the well-established "Kyoto protocol", it behooves the concrete industry to reduce CO_2 emissions because the greenhouse gases originating from concrete production and application are hazardous. They also need to target enhancements that reduce carbon footprint. The life cycle of concretes which includes raw materials, production, and optimization of mix design, use, demolition, and recycling of concretes must become an environmentally friendly process. These challenges are met by using environmentally beneficial materials that are renewable and sustainable. It is also obvious that there is a large amount of CO_2 production and energy consumption for every tone of cement and concrete produced due to thermal processes. Hence, the emergence of blended/reinforced cement and concretes will eventually lead to tailor-specific concrete applications for concrete type-structures. Moreover, when suitability is achieved, sustainability will drive down costs and promote energy savings. In addition, transport of aggregates from quarry to consumption is energy-intensive but an obvious green solution of PSP/PSA as cement aggregates can technically minimize the need for binders and cement. Overall, nanoparticles improve material capacities related to durability and mechanical properties, care has to be taken that PSP/PSA reinforcements as green materials do not result in not-so-green concretes; wherein durability and mechanical properties are compromised. Summarily, the requirement of national industry standards differs across nations, but it is necessary to implement standards that capture the production of PSP/PSA aggregates as green materials in the building and construction industry [81–84].

4.4 Economics

Concrete is a major component of a building, and its production cost significantly affects the overall cost of building projects across the world. These have led to abandoned projects and compromised building quality due to the rising cost of building materials, especially in developing countries. Several attempts have been made to partially replace or wholly substitute the constituents of concretes with natural and synthetic materials. This anticipation has driven research towards sourcing for indigenous, cheap, and friendly materials that can wholly or partly replace the imported and costly materials as well as reduce market competition among cement producers and market monopoly of granite/gravel in extreme cases.

Provided these composite materials meet the desired engineering characteristics for concrete construction, considerable effort has to be taken to improve not only the strength and durability of concretes but also cost reductions, through the use of local pozzolanic materials. Among such pozzolanic consists of the growing interest in periwinkle shells disposed of as agricultural waste and dumpsite pile-ups. The utilization of PSP/PSA in construction has to become profitable for its benefits to be derivable. Some of the derivable benefits include supplementing cementitious and concrete composites with PSP/PSA which is a renewable, sustainable, less hazardous, cost-effective, and energy-saving option. The cost of the shell is 100 times less than gravel, granite, and cement, and in some cases. a free waste-material requiring that needs disposal or recycling. The PSP/PSA materials can in the long run cushion the rising cost of construction materials in lightweight concretes. This will improve carbon capture, CO_2 emission from cement production, which is a high energy-intensive process, notorious for greenhouse gas emission.

A challenging factor to this development is that periwinkle is ecologically found in brackish waters, mangrove swamps, and muddy flats as well as coastline regions of the world. Moreover, not so much is known by a marine biologist about the population ratios across the world neither have farmers taken it up as a lucrative business for rearing, harvesting, and shell processing for construction purposes in most parts of the world. These may have significantly impacted the research advancement given that only a handful of publications on periwinkle reinforcements/filler in concretes are available. More so, investors and research funders are yet to consider PSP/PSA as a viable and profitable option, neither have researchers taken an intense interest in this material. Thus, the economics of this material are dependent on marine reserves, large-scale cultivation, research innovations, and research funding. Hence, a concerted effort is needed to achieve the full-scale utilization of PSP/PSA as a partial or whole replacement of buildings in concretes and buildings for cost savings. Until then, the rising cost of building materials is inevitable, while the functional benefit of PSP/PAP delines, and the sustainability development remains inept and ungainly [45,50,59,66].

5. CONCLUSION AND RECOMMENDATION

The progress of periwinkle shell and periwinkle ash in concretes and cements is challenging andfrom the results of this study, the following conclusions can be drawn:

- Over the years, its advancement has been affected by poor funding, deprived research interest, discordant research, and the non-commercialization of periwinkle farming.
- The problems have hampered the growth and development of this material as a composite material in cementations building and concrete construction, without providing the solution.

- The absence of nanoscience and nanotechnology in the application of PSP and PSA as composites in concretes compounds the problem. This knowledge gap creates a research opportunity for researchers to investigate the interaction as well as the mechanism of PSP/PSA with concretes and cement.
- Then again, the preparation for PSP/PSA was mainly via physical treatments. It becomes necessary, therefore, to investigate the effect of the chemical treatment of PSP and PSA in concretes and cements to enhance their mechanical properties and thermal properties.
- Also, most findings reported 10-30 % replacement of concrete materials by PSP/PSA as optimum. This information is also useful in the formulation of concrete composites because interesting research can be carried out on how variations of several parameters and variables change when PSP/PAP is kept constant during concrete production.
- Additionally, robust instrumentation like atomic force microscopy, x-ray diffraction, and Scanning electron microscope, and transmission electron microscopes are needed to elucidate the morphological interaction of cementations behavior in the concrete formulation.
- Finally, the study is required to extend beyond the production of lightweight concretes using PSP/PSA. Beyond aesthetic purposes, studies involved periwinkle composites incorporated into buildings and construction of pavements, silos, sewers, roofing, water containment structures, and tunnels and should be carried out. Until then, the rising costs of building materials are inevitable and housing development remains expensive. Researchers must then find a sustainable, renewable, less hazardous, and cheap material. Till then, the prospects of PSP/PSA have made it a potential future composite in reinforced concretes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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