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Utilization of Mollusc Shells for Concrete Production for Sustainable Environment

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Abstract — The ability to reduce, reuse and recycle mollusc shell waste for civil and construction engineering applications is an attractive component of integrated waste management scheme. This paper presents the applicability of mollusc farming residues especially the shells and shell-ash in partial or full replacement for coarse aggregate and ordinary Portland cement (OPC) respectively. The chemical constituents of mollusc shell ashes at 800^{o}C which qualify as pozzolans are comparable with the conventional cements. The physical properties and size distribution of periwinkle, cockle and oyster shells qualify for coarse aggregate which with paste and fine aggregate produce lightweight concrete without jeopardizing strength. Finally, the durability of concrete so-produced from shell-coarse aggregate is guaranteed at a maximum temperature of 300^{o}C and the shell ash-blended cement concrete under sulphate attack experienced the least reduction in compressive strength.

Index Terms— Compressive strength, shell aggregate concrete, durability of concrete, shell-ash blended cement.

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1 Introduction

CONCRETE, the most widely used construction material, plays a vital role in global economic growth and infrastructural development. The socio-economic growth, industrial development and the overall well-being of any nation are directly connected to the adequacy, functionality, reliability its infrastructure. The continuous expansion of the built environment causes the depletion of natural aggregates with an attendant effect on the cost of concrete. To keep the cost concrete production affordable while maintaining sustainable environment, several investigations have been carried out in the past dedades on utilization of demolition wastes as aggregates in concrete [1], [2], [3], [4]. Other natural and synthetic wastes such as pulverized fly ash [5], [6]; slag [7]; rice husk ash [8], [9]; and sawdust ash [10] have also been experimented as blended-cement and additives in concrete. Adewuyi and Ola [11] and Smol et al. [12] studied the applicability of water treatment sludge ash and sewage sludge ash respectively as partial replacement for cement in concrete and bricks. Mollusc shells have found usage either as coarse aggregates or as ash-blended cement for concrete production.

Most commonly investigated mollusc shells are periwinkle (Littorina littorea), cockle (Cerastoderma edule), and land snail (terrestrial gastropod molluscs). Periwinkle is a species of small edible sea snail (marine gastropod mollusc) whose shell is disposed of as waste.

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Periwinkle shell is a V-shaped spiral, round aperture, very strong, hard and has brittle material properties. Many of the land snails live in habitats or microhabitats that are sometimes (or often) damp or wet region. In Nigeria, particularly, mullusc shells have been employed as coarse aggregates for lightweight concrete in many parts of Niger Delta region where granite chippings and natural gravels are extremely scarce. Though the shells are relatively thin, it has also found tremendous application as ash-blended cement. Cockle is a group of small, edible, saltwater clams, marine bivalve molluscs which live in sandy, sheltered beaches throughout the world. Their shells are typically processed for domestic and industrial use after removing the inedible ones. Locally, the applications of snail shells range from construction of walkways, pavement slabs, building, filling materials, erosion control, well casing, shore line, road and bridge construction [13].

From global perspectives, a range of research areas has helped to develop the use of shell in specific applications. Environmentally, the utilization of mollusc shell in anaerobic water treatment systems for heavy metals removal and filtration has been reported in literature [14]. Extensive studies have reported the efficiency of these systems for remove heavy metals, oils and microbial contamination from surface waters. An overview of some of these research areas includes the applicability of mollusc shell ash-blended cement for concrete production, and partial or full application of periwinkle, cockle, and oyster shells as coarse aggregates in constructed concrete facilities. The use of shell in lime production for sustainable masonry applications is one major application for affordable housing. Shells have been utilized in permeable paving for sustainable urban drainage systems [15]. Shell replacement has been explored by the Environment Agency with laboratory work undertaken on the potential use of cockle and whelk [14]. This study has provided samples of other species such as scallop for further testing of leachable components.

It is evident that the natural resources consistently deplete while the demand for concrete constituent materials still remains increasingly high. Hence, diverse waste materials have been investigated for reuse and/or recycling in full or partial replacement for coarse aggregate in concrete production such as periwinkle shells [16], [17], [18], cockle shells [18] among several others. This is a usual practice among the average residents of riverine and other areas where gravel and granite are not locally available particularly where lightweight concrete is required for non-load bearing walls, non-structural floors, strip footings and other non load-bearing structural elements.

Singh *et al*. [19] and Umoh and Olusola [20] investigated the use of bamboo leaf and periwinkle shell ashes as partial replacement for OPC, and the results showed that they are good supplementary cementitious materials as they are amorphous in nature and has good pozzolanic properties. Utilizing the ash of the mollusc shells, up to 50% replacement of cement in sandcrete blocks and 5% replacement in laterite blocks were possible with good compressive strength [21]. Furthermore, extensive research findings in recent times have revealed that cementious blends should not exceed 35% replacement of cement [22]. Periwinkle, oyster and snail shell ashes were substituted for OPC in concrete production [23] and the pozzolanic properties satisfied the requirements of ASTM [24] for cementitious materials. Umoh and Olusola [25] and Olusola and Umoh [26] investigated the effect of periwinkle shell ash (PSA) as cement substitute on the strengths of concrete grade 25 N/mm^2 up to a curing age of 180 days. The finding revealed that maximum PSA content of 10% is adequate as cement substitution for structural concrete.

Orangun [27] pioneered the investigation on the suitability of periwinkle shells as coarse aggregates and reported that the strengths of such concretes were limited by the strength of the shells but satisfactory enough for structural concrete. Studies on different concrete mixes made with periwinkle shells, though lightweight, resulted in compressive strength in excess of 15 N/mm^2. The modulus of rupture and the strength of periwinkle-shell coarsed reinforced members in direct compression were comparatively lower, but flexural members had satisfactory strength with larger ductility than those made of normal gravel concrete. Falade [28] further investigated the usefulness of periwinkle shells (PWS) partially or wholly in concrete. Volumeric mix design approach was employed for concrete containing 100% periwinkle shells. The results of the investigation showed that the workability of the concrete batches, density, compressive and flexural strengths of specimens tested decreased with increase in the proportion of periwinkle shells-granite ratio in the mixes. Osarenmwinda and Awaro [29] studied the potential of periwinkle shell as coarse aggregate for concrete. The results showed that concretes produced with 1:1:2, 1:2:3 and 1:2:4 mixes gave compressive strengths of 25.67, 19.50 and 19.83 N/mm^2 respectively at 28 days curing age. These strength values satisfied the ASTM minimum requirement of 17 N/mm^2 for structural lightweight concrete. Figure 1 shows the images of typical shells of snails, periwinkle and cockle employed in concrete production and construction works.

(a) (b) (c)

Figure 1. Shells of typical (a) snails, (b) periwinkle and (c) cockle.

Adewuyi and Adegoke [16] carried out an exploratory study of periwinkle shells as coarse aggregates in concrete works and concluded that 35.4% and 42.5% replacement of crushed granite with periwinkle shells by weight give concrete

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with acceptable compressive strengths. These resulted in savings of 14.8% and 17.5% of material cost for 1:2:4 and 1:3:6 concrete mixes respectively. Ibearugbulem [30] classified the shells as lightweight coarse aggregates in accordance with ASTM specifications for concrete. Osayemwen [31] assessed the utilization of periwinkle shells as alternative material to crushed granite as coarse aggregate in concrete and concluded that the use of periwinkle shells for concrete would result in low cost housing delivery especially in the riverine areas where they are abundant as waste. Muthusamy and Sabri [18] investigated the suitability of cockle shell as partial replacement for coarse aggregate in concrete. The results showed that cockle shell-coarsed gave adequate workability and satisfactory strength. Introduction of 20% cockle shell as coarse aggregate enhanced the strength of concrete making it the optimum compared to any other replacement level.

The thrust of this paper is to evaluate the performance of mollusc shells (periwinkle, oyster and cockle) as aggregates and the shell ash in partial replacement for ordinary Portland cement (OPC) in concrete production. The durability assessments of such shell ash-blended and shell-coarse cement concrete at elevated temperature and under the influence of sulphate attack are presented.

2 Experimental Investigations

The shells were calcined in a furnace to form ash at 800 ^oC temperature for 2 hours. The various shell ashes namely periwinkle shell ash (PSA), oyster shell ash (OSA) and snail shell ash (SSA) were ground and sieved through a sieve mesh size of 63 microns for analyses. The specific gravities for PSA, OSA and SSA were 2.50, 2.33 and 2.44 respectively. The chemical composition/constituents of PSA, OSA and SSA were compared with OPC as shown in Table 1. The results showed that shell ashes contained the main chemical constituents of Portland cement namely CaO, SiO_2 and Al_2O_3 with high percentages of CaO and SiO_2 which accounts for its strength. The chemical constituents of the three shell ash types are indeed comparable.

Particle distribution analysis was carried out on natural sand, natural gravel, periwinkle coarse shells (PCS), cockle coarse shell (CCS), ordinary Portland cement (OPC), PSA, OSA and SSA to determine its gradation in accordance with ASTM C 204 as shown in Figure 2.

The results showed that the particle sizes of the periwinkle shells ranged from 6.7 to 26.0 mm maximum size with dry density of 1437 kg/m^3 and a total of 33.1% by weight of the periwinkle shells were retained on 12.5 mm sieve while 10.7% were retained on 9.5 mm sieve. Cockle shells sizes ranged from 8.0 to 15.0 mm maximum size with dry density of 977 kg/m^3 and a total of 85.2% by weight of the cockle shells were retained on 12.5 mm sieve while 27.0% were retained on 9.5 mm sieve. Batching by weight was considered for the materials used in the production of control, PCS and CCS concrete mixes, and the shells ash (PSA, SSA and OSA) in a mix ratio of 1:3:6 concrete mixes (cement:sand:coarse) corresponding to 15 N/mm^2.

TABLE 1
CHEMICAL COMPOSITION OF PORTLAND CEMENT AND THE MULLUSC SHELL ASH OBTAINED AT 800 ^OC

Chemical constituents	Composition (% of weight)			
	OPC[a]	PSA[b]	OSA[b]	SSA[b]
SiO_2	21.20	26.26	13.41	10.20
Al_2O_3	5.47	8.79	4.95	4.81
Fe_2O_3	3.31	4.82	3.30	3.15
CaO	62.52	55.53	57.95	61.95
K_2O	1.71	0.20	0.02	0.05
Na_2O	0.46	0.25	0.22	0.04
SO_3	1.90	0.18	0.12	0.03
MgO	1.97	0.40	0.19	0.18
P_2O_5	-	0.05	0.01	0.01
MnO_3	-	0.07	0.01	0.01
TiO_2	-	0.05	0.01	0.01
Loss of ignition	1.46	-	-	-

Source: [a]Limbachiya [32], [b]Etuk *et al*. [23]

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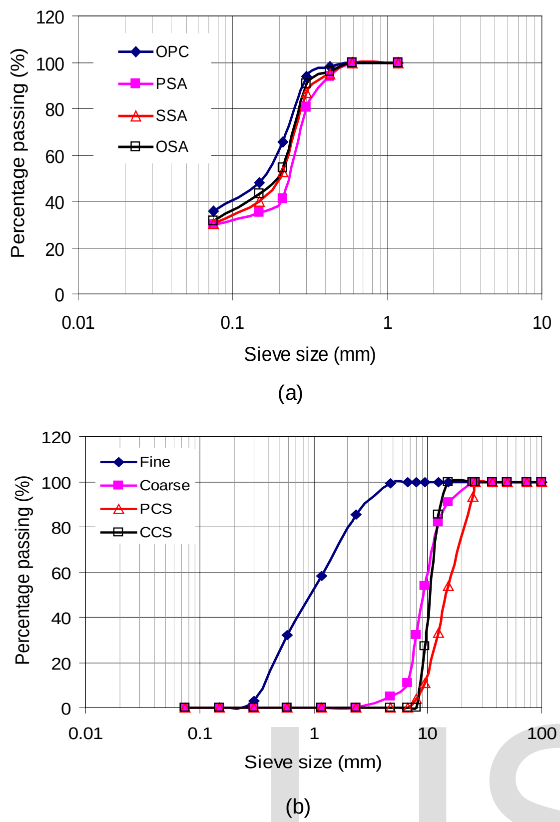

Figure 2. Particle size distribution of (a) OPC, and mollusc shell ashes; (b) fine and coarse aggregates, periwinkle and cockle shells.

Thorough mixing was done for every percentage of PCS and CCS in the concrete batch separately in a laboratory mixer for some minutes to ensure adequate mix and give homogeneous concrete mixture. Similar procedure was employed for the PSA, SSA and OSA blended-cement concrete. Varying percentage replacements for cement were considered. The hardened properties of concrete samples were also determined from 150 mm concrete cube specimens.

3 Experimental Findings

3.1 Mollusc Shell Ash-blended Cement Concrete

All the cast specimens were covered with layers of water-saturated burlap and polyethylene sheets in the laboratory for 24(±2) hours. The specimens were subsequently demoulded, transferred to and cured in a standard water tank at 20(±5) °C until the age of testing. The cubes were removed at the end of 7, 14, 21 and 28 days respectively from the day of casting, dried at room temperature for an hour, weighed for density check and tested for their compressive strength in accordance with BS 1881 [33]. Figure 3 shows the 28th day compressive strength for PSA, SSA and OSA. Whereas PSA and OSA had the optimal strengths at 10% and 15% ash replacements respectively corresponding to 18.75 and 18 N/mm², SSA had the optimal strength of 17 N/mm² at 20% ash content.

Figure 4 shows the consistency and compressive strength results for grade 25 shell ash-blended cement concrete. It is evident that 10% ash content conveniently satisfied the strength requirements and the ashes showed good waster consistency comparable with cement. As the percentage replacement of each of the shell ashes increased, so did consistency. The initial and final setting times of the blended cement pastes also increased.

3.2 Solid Shell as Coarse Aggregate in Concrete

The strength of grade 25 shell ash-blended cement concrete produced from PCS and CCS are shown in Figure 5. The compressive strength decreases as the percentage of periwinkle shells increased in PCS concrete. The minimum requirement of 25 N/mm² was satisfied with 40% and 10% replacements of periwinkle and cockle shells aggregate respectively in concrete [34], [35].

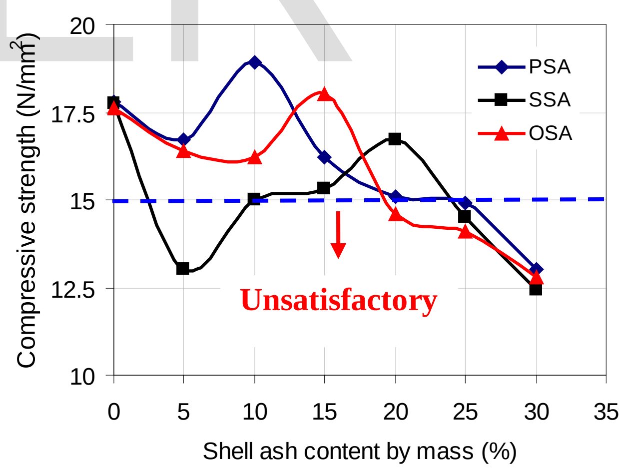

Figure 3. Compressive strength of shell ash-blended cement concrete at 28th day

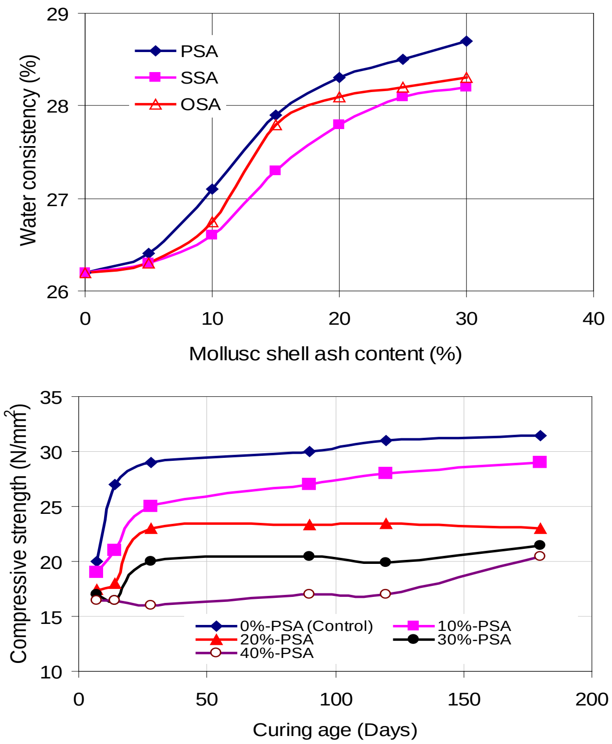

Figure 4: Water consistency and compressive strength for varying ash contents

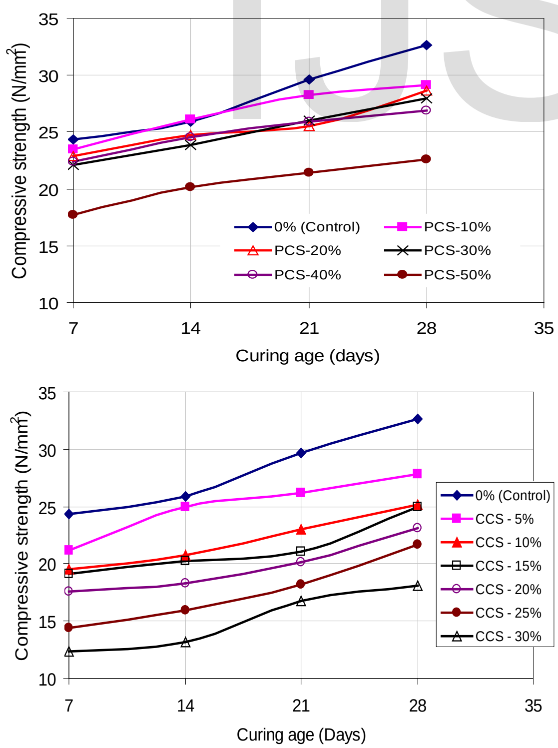

Figure 5: Compressive strength of PCS and CCS as coarse aggregate in concrete

4 Durability Assessment of Shell Concrete

4.1 Durability Assessment of Coarse Shell Aggregates at Elevated Temperature

Full periwinkle coarse shell concrete (100% PCS) cubes were subjected to heating between 50 and 800 °C/hr in carbolite furnace oven with regulated temperature up to 1000 °C. There was no significant difference in the physical appearance of samples at temperature up to 300 °C, and so were the physical and strength properties as shown in Figure 6. The concretes exhibited minor signs of cracking and spalling on the exposed surface at temperature between 300 and 400 °C. Major cracks were noticed on the specimens between 400 °C and 600 °C, while combustion characterized by smoke emission was obvious within 700 - 800 °C. Due to high volume of smoke emitted at 800 °C, heating was terminated to avoid fire or explosion of the cube specimens in the oven. At 800 °C temperature, the colour of the periwinkle shells changed from black to brownish. Thus, PCS concrete is not recommended for use in heat-resistant structures [36].

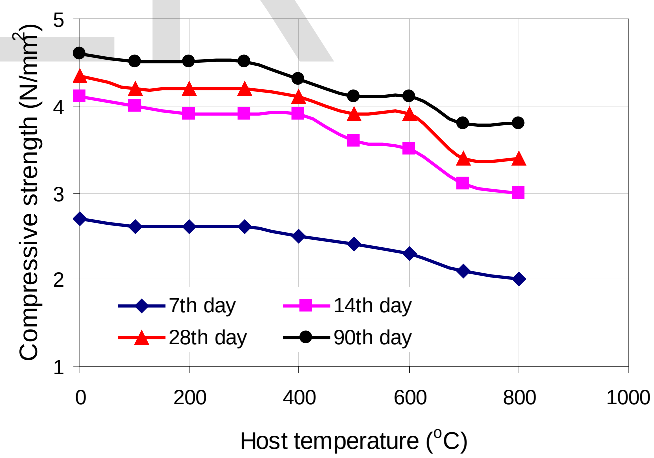

Figure 6: Behavior of lightweight periwinkle coarse-shell aggregate concrete at varying exposure temperature [36].

4.2 Resistance of Shell Ash-blended Cement Concrete to Sulphate Attack

Some set of PSA concrete cubes were immersed in sulphate solutions to assess the effect of 5% concentrations of $MgSO_4$, Na_2SO_4 and $CaSO_4$ on the compressive strength of PSA blended cement concrete [26]. Initially, there was a dramatic

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increase in the compressive strengths of PSA blended cement concrete on exposure to sulphate attack between up to 3 months, but the strength reduction became much remarkable with increase in exposure age particularly at 6 months. The deleterious effect of the sulphate salt solution on the concrete compressive strength is highest on the control than other concrete specimens with various percentages of PSA replacement levels with cement in the order $MgSO_4$ > $CaSO_4$ > Na_2SO_4. It is evident that the shell ash-blended cemetitious materials enhanced the resistance to suphate attack.

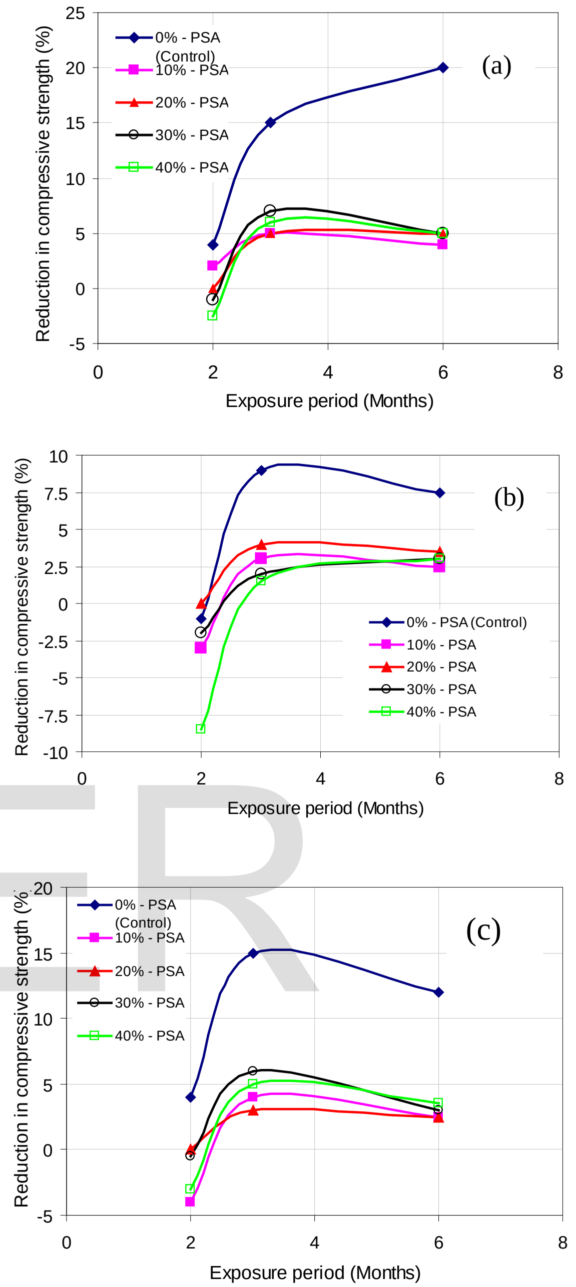

Figure 7: Reduction in compressive strength of PSA blended cement concrete exposed to 5% of (a) $MgSO_4$, (b) Na_2SO_4 and (c) $CaSO_4$ solutions.

5 Conclusion

Based on the findings of this investigation, the following conclusions were made:

1. The 3Rs (reduce, reuse and recycle) of integrated waste management are effective in shell wastes and applicable to civil construction works.

2. Both the coarse shells and the ash are effective as aggregates and blended cement up to 100% and 10% respectively.
3. The concrete having up to 40% periwinkle shells and the one with 10% cockle shells inclusion can be regarded as normal weight concrete, while higher contents imply lightweight concrete.
4. Periwinkle shells concrete is recommended for use where moderate temperatures of less than 300 ^{o}C and ash-blended cement concretes have higher resistance to sulphate attack.

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