Nigerian Journal of Technology
Vol. 40, No. 1, January, 2021, pp. 13–18.
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v40i1.3

Performance of Sand-Crushed Oyster Shells Blended Fine Aggregates in Concrete: Waste Management Perspective in Nigeria

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Abstract

Pollution of our environment with wastes and the associated harm to our ecosystem and health is of great concern globally. In addition, the unabated mining of sharp sand for concrete with environmental degradation arising therefrom is worrisome. In the Niger Delta region of Nigeria, enormous quantities of oyster shells are being littered along the streets, riverbanks and landfills, after eating the fleshy part as meat. As a means of managing the waste and conserving sand, this study examines the properties of concrete made, using crushed oyster shells (COS) as partial replacement of sand. Sand was partially replaced in concrete with COS at the rate of 0, 5, 10, 15, 20 and 25%. The concrete matrix was cast in a metal cube mold of 150mm^3 and cured for 3, 7, 14 and 28 days. A total of 72 cubes were cast in three replicates for each replacement level and each curing period, using a standard mix of 1:2:4 and water-cement ratio of 0.5. The results reveal that the addition of COS reduces the slump of the fresh concrete from 27 mm at 0% to 20 mm at 25%. The addition of COS up to 25% reduced the density of the concrete by 4.05%. The compressive strength slightly reduced as the percentage replacement increased from 0 to 25%. The findings recommend replacement not exceeding 15% that has true slump of 23.5 mm, lighter density of 25.17 kg/m^{-3} and compressive strength of 26.2 Nmm^{-2} which are good for concrete works. When sand is partially replaced with COS in concrete, we can confront the environmental degradation arising from indiscriminate disposal of oyster shells, as well as the depletion of sand as non-renewable component of concrete.

Keywords: concrete, crushed oyster shells, environment, partial replacement, sand

1. INTRODUCTION

In Nigeria, the disposal of waste materials from agricultural and industrial operations like palm bunches, coconut shells, palm kernel shells, used tyres, snail shells, animal bones, wastepapers, seashells, and so on has been a source of worry [1]. The search for alternative cheaper materials and utilization of industrial wastes and by-product materials in infrastructure development is proven economically viable when environmental factors are considered and these materials meet appropriate performance specifications and standards [2]. The availability of sand for construction works is becoming rare due to the excessive mining as a result of increasing demand for shelter and other infrastructural facilities, especially in the developing countries, like Nigeria. This has resulted in high cost of sand for construction works [3]. The over-exploitation of non-renewable natural materials has caused sharp increase in its cost [4]. Oyster aquaculture is one of the key businesses in island nations [5]. Molluscs aquaculture is advocated as a highly sustainable food source. One of the regularly overlooked aspect of aquaculture is its waste generation, which is regarded as nuisance to our environment [6]. Between 2008 and 2012, Taiwan generated 300,000 tons of oyster shells, which calls for environmental concerns [7]. In South Korea, there were excess oysters; hence, can be utilized in the construction industry [8]. Approximately three hundred thousand tons of oyster shells occur in South Korean seas annually. Only a very small percentage is re-used. Hence, there exists the problem of disposing the remnant of the waste oyster shells. This results in illegal disposal in the surrounding area.

In a particular year in Taiwan, the yield of oyster shells was 34,000 megatons. After shelling, the total quantity of oyster shells produced globally was approximately 200,000 megatons. However, only a very small portion is recovered and

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Figure 1: Drying of washed oyster shells under the sun.

reused, according to Department of Fisheries Administration, Yuan, Taiwan [9]. In Nigeria, oyster shells are found in the Niger Delta region located at latitude 5.3261°N and longitude 6.4708°E. Niger Delta is the delta of the Niger River at the Gulf of Guinea on the Atlantic Ocean in Nigeria. The region has a tropical climate with two distinct wet and dry seasons. The mean annual rainfall usually exceeds 3500 mm along the coast. It has annual mean temperature of between 18 to 35 ℃[10]. These make the Niger Delta region a good habitat for oysters; hence, enough waste shells. The nine Nigerian states comprising Niger Delta region are found in the swamp/fresh water forest ecological zone. Worldwide, between 8 and 10 billion tons of concrete is produced annually. Such amount of concrete requires higher amounts of natural resources for aggregates [11]. Time will soon come when all sources of natural aggregates will decrease [12]. Consequently, alternative fine aggregates for concrete has become imperative. Oyster shell is a sea food which result to waste after consumption, causing environmental hazard due to pollution. If crushed oyster shells is used as substitute for fine aggregates, charges for disposal of waste will be avoided. Oyster shells are composed of calcium carbonate, $CaCO_3$ (approximately 96%) and other minerals in trace amounts [13–15]. As a result of this predominant chemical composition of oyster shells with $CaCO_3$, some researchers, [16–19] have crushed and used its powder to partially replace cement in either mortar or concrete due to its resemblance in chemical composition with limestone used in the production of ordinary Portland cement. When crushed oyster shell (COS) powder is used in partial replacement of cement, the chaff has resemblance with sand. Hence, can partially or fully replace sand in concrete. This research therefore explores the properties of concrete produced with COS as partial replacement of sand in concrete, having waste management of waste oyster shells in Nigeria in focus.

2. MATERIALS AND METHODS

2.1. Materials

The cement used in this work was Dangote brand and it conformed to the requirements of [20]. The sharp river sand was sourced from Ovim River in Isuikwuato Local Government Area of Abia State, Nigeria. The well graded sharp sand was free from deleterious substances and it conformed to the requirements of [21]. It was thoroughly flushed with water to reduce the level of impurities and organic matter. The granite of 20 mm maximum size was sourced from the quarry belonging to Setraco Construction Company, Amasiri, Ebonyi State, Nigeria and it conformed to the requirements of [22]. The water used for the study was obtained from borehole sunk in the College of Engineering and Engineering Technology, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. The water was clean and free from any visible impurities. It conformed to the requirements of [23]. Oyster shells used for this research were collected from where they were obtained from Waterfront and Creek Road where they were discarded Port Harcourt, Rivers State, Nigeria, where they were discarded, having taken by the fleshy part of the oyster as food.

2.2. Methods

In order to remove the little flesh attached to the oyster shells, the oyster shells were soaked in water for about 48 hours and thoroughly washed. The shells were sun-dried and crushed mechanically with the aid of the Hammer Mill Machine of brand TFR400. Figure 1 shows where the washed oyster shells were undergoing drying under the sun, while Fig. 2 shows the crushed oyster shells awaiting sieving.

Having confirmed that the sand, granite, cement, crushed oyster shells conformed to the relevant British Standards, we used standard mix of 1:2:4 of binder: sand/COS: granite at water-cement ratio of 0.5 with target strength of 25 N/mm^2. Sand was partially replaced with COS at

Figure 2: Crushed oyster shells while awaiting sieving in the laboratory.

Table 1: Mix proportions for partial replacement of sand with crushed oyster shells.

Specimen	Mass of water (kg)	Mass of cement (kg)	Mass of sand (kg)	Mass of granite (kg)	Mass of crushed oyster shell (kg)
K-0	7.776	15.552	31.104	62.208	0
K-5	7.776	15.552	29.549	62.208	1.555
K-10	7.776	15.552	27.994	62.208	3.110
K-15	7.776	15.552	26.438	62.208	4.666
K-20	7.776	15.552	24.883	62.208	6.221
K-25	7.776	15.552	23.328	62.208	7.776

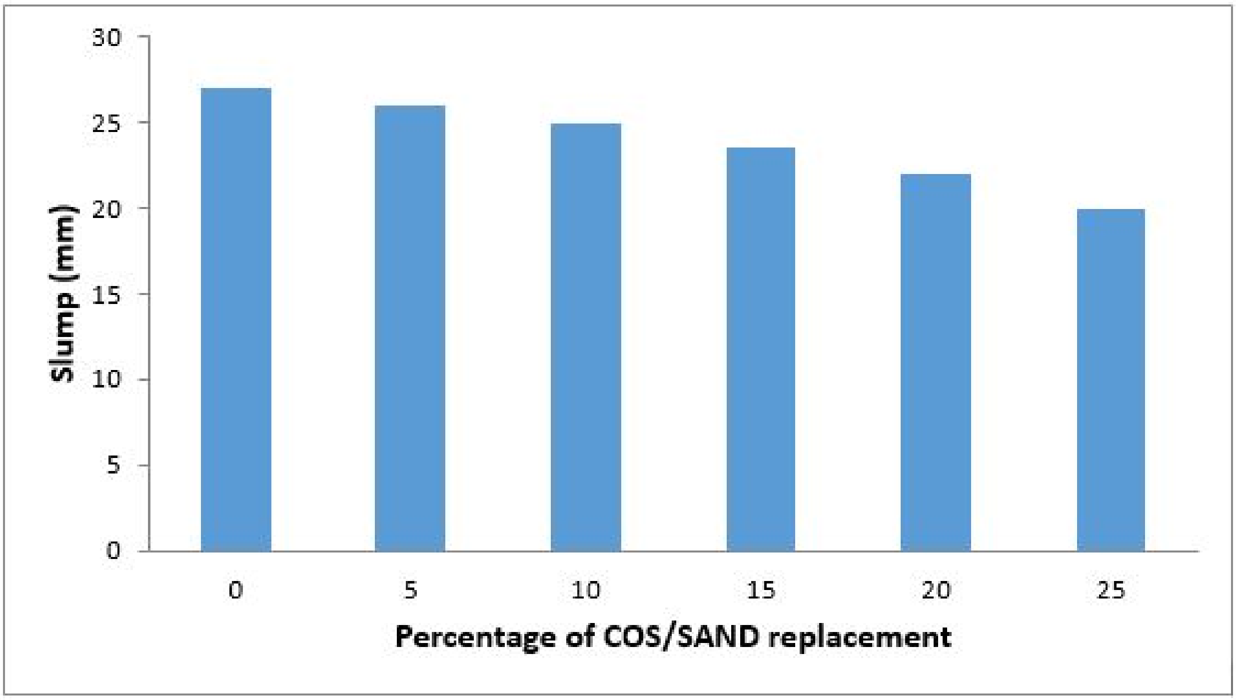


Figure 3: Variation is slump of COS-sand concrete as percentage replacement varies.

Table 2: Mix proportions for partial replacement of sand with crushed oyster shells.

COS replacement level (%)	**Density of concrete** (kg/m^3)				**Average density** (kg/m^3)
	3 Days	**7 Days**	**14 Days**	**28 Days**	
0	2601	2590	2631	2619	2619
5	2578	2524	2625	2634	2590
10	2545	2604	2563	2486	2550
15	2560	2557	2447	2504	2517
20	2489	2507	2530	2527	2513
25	2462	2601	2450	2477	2498

the rate of 0, 5, 10, 15, 20 and 25%. The homogenized mixture was cast in concrete cube molds of 150 × 150 × 150mm, in layers of 50mm and compacted with the tamping rod at 25 strokes per layer and the top finish with the trowel and label accurately conforming to [24]. The concrete cubes were released from the metal molds after 24 hours and immersed for 3, 7 ,14, and 28 days in a curing tank. A total of 72 cubes of concrete were cast. After the test for setting times of cement and grading of aggregates were done to ascertain the suitability of the materials, the workability, density and compressive strength of the concrete were also examined. Each sample was replicated thrice for each curing period and for each replacement level. Density is calculated from Eq. (1):

$$\text{Density} = \frac{\text{Mass of concrete cube in kg}}{\text{Volume of concrete cube in m}^3} = \frac{\text{Mass}}{0.15 \times 0.15 \times 0.15} \quad (1)$$

After obtaining the crushing load (load at fracture) from the universal testing machine of brand OKH-200, where load of uniform pace of 5.25 KN/Sec was applied and maintained, the compressive strength is calculated using Eq. (2);

$$F_{cu} = \frac{\text{Crushing Load in N}}{\text{Area of concrete in mm}^2} \quad (2)$$

The mix proportions are as given in Table 1.

3. RESULTS AND DISCUSSION

3.1. Workability of Sand-COS Concrete

The workability of the fresh sand-COS concrete as the percentage replacement increased from 0 to 25% is shown in Fig. 3.

It can be seen that concrete became less workable as the percentage of COS increased from 0% to 25%. The slump decreased from 27 mm at 0% to 20 mm at 25% replacement levels. This is similar to the results of [7, 25]. This is attributable to sharper and irregularly shaped particles of the COS, resulting in lowered fluidity and higher friction. However, the concrete is still of good workability and has ease of placement, despite the reduced slump.

3.2. Density of Sand-COS Concrete

The variation in average densities of standard and COS-sand concrete after each curing period are shown in Table 2.

As the percentage replacement of sand with COS increases, the density of concrete continues to decrease, leading to concrete of lighter weight. This is as a result of lower specific gravity of COS than sand. Consequently, there is reduced dead load of the structure. This is advantageous as the ability of the structure to resist loads is enhanced. For instance, the density reduced from 2619 kg/m^3 at 0% to 2515 kg/m^3 at 25% replacement. Thus, partial replacement of sand with COS up to 25% produces concrete that is 4.05% lighter than the standard concrete. This is because the specific gravity of COS is less than that of river sand.

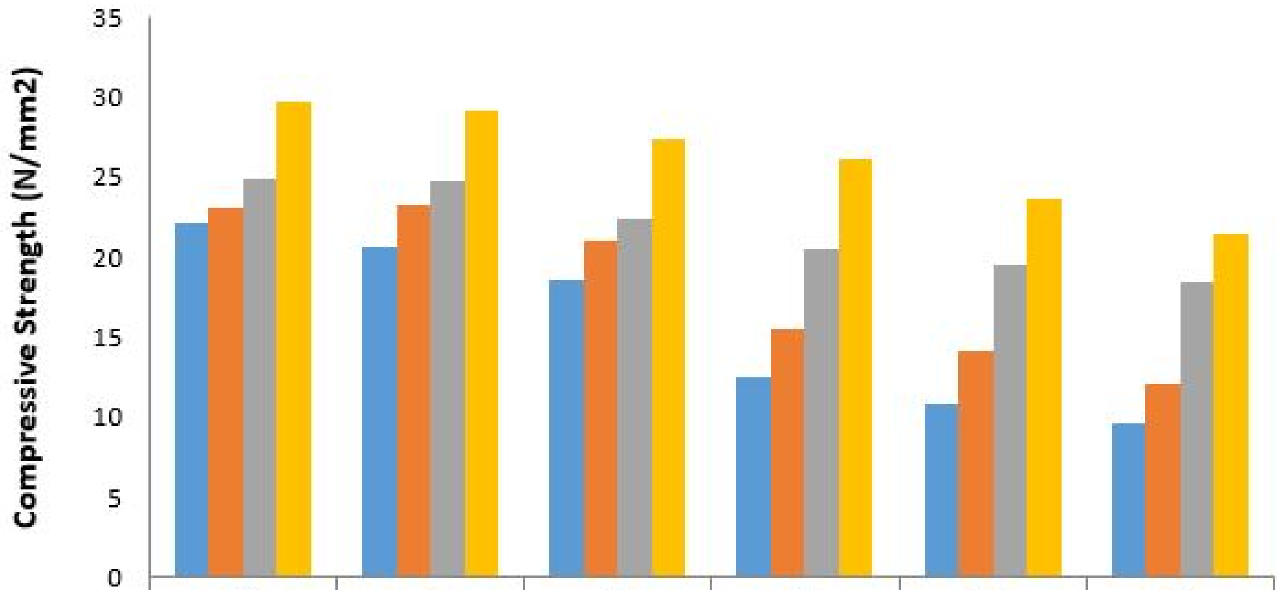
3.3. Compressive Strength of Sand-COS Concrete

Figure 4 shows that there was a general increase in compressive strength as the curing age increases from 3 to 28 days. The compressive strength of concrete of COS-sand concrete continued to decreases slightly as the percentage replacement increases. Figure 4 shows that the 28-day compressive strength of COS-sand concrete met the target strength of 25 N/mm^2. The compressive strengths for 5, 10, and 15% are respectively 29.2, 27.4, and 26.2 N/mm^2. This agrees with the results of [7, 23]. This is as a result of porous structure and lower absorption rate that leads to slower hydration of cement. Hence, lower compressive strength. When concrete of slightly lower strength is needed, higher percentage replacement is advised.

4. CONCLUSION

The present study focused on investigating the rheological and hardened properties of concrete produced using the readily available crushed oyster shells as partial replacement of sand, with emphasis on managing the environment of the Niger Delta region of Nigeria. From the foregoing results and discussion, the following conclusions are hereby drawn:

(a) The addition of COS to partially replace sand from 0 to 25% reduces the workability (slump) of concrete. However, the concrete is still of good slump. Hence, workable.



	0	5	10	15	20	25
3DAYS	22.1	20.6	18.6	12.5	10.8	9.6
7DAYS	23.1	23.3	21.1	15.5	14.2	12.1
14DAYS	24.9	24.8	22.4	20.5	19.6	18.4
28DAYS	29.8	29.2	27.4	26.2	23.7	21.5

Figure 4: Variation of compressive strength of sand-COS concrete at with curing age.

(b) Sand-COS blended concrete is slightly less dense than the normal concrete. This will lead to reduced dead load of the structure. Hence, sand-COS concrete produces lighter weight concrete.

(c) As the percentage replacement of sand with COS increases, compressive strength slightly reduces. However, the compressive strength is generally good.

(d) The compressive strength of sand-COS increases as the curing age increases.

(e) Replacement level not exceeding 15% for reinforced concrete is recommended for sand-COS fine aggregates as a waste management approach in the Niger Delta region of Nigeria for healthier environment and reduced associated health hazards is hereby recommended.

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