CHARACTERIZATION OF COCONUT SHELL ASH AND EGGSHELL POWDER AS SUPPLEMENTARY CEMENTITIOUS MATERIALS IN ROLLER COMPACTED CONCRETE INDUSTRIAL ACCESS PAVEMENTS AND PARKING FACILITIES.

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Abstract

The cost of cement used in concrete works is on the increase and unaffordable, yet the need for hydraulic cement concrete and other cement concrete based infrastructures keeps growing with increasing population, thus the need to find alternative binding materials that can be used solely or in partial replacement of cement. The use of waste materials with pozzolanic properties in concrete production is becoming a worldwide practice. The assessment of the pozzolanic activity of cement replacement materials is becoming increasingly important because of the need for more sustainable cementing products. In this study, a mixture of coconut shell ash and eggshell powder is used as partial replacement of hydraulic cement in ranges of 0%, 5%, 10%, 15%, and 20%. The concrete specimens were prepared at 1: 3: 2.5 mix ratio of cementitious material, fine aggregate and coarse aggregate. The mix ratio satisfied the minimum cement content of 148.32kg/m^3 (250lb/yd^3) and the minimum cementitious material content of 267 kg/m^3 (450lb/yd^3) for roller compacted concrete pavement. The compressive strength, splitting tensile strength and flexural strength tests were carried out to assess the strength characteristics of ternary concrete mixture containing coconut shell ash and eggshell powder and the feasibility of using coconut shell ash and eggshell powder as partial replacement of cement in industrial plant access concrete roads and parking lots. The results indicate that a mixture of coconut shell ash and eggshell powder can be used up to 20% by weight for replacement of cement in roller compacted industrial plant access concrete roads and parking lots.

Keywords: Cement, coconut shell ash, compressive strength, eggshell powder, flexural strength, parking lots, and roller compacted industrial access roads.

1. INTRODUCTION

Concrete is widely used as construction material for various types of structures due to its durability. Cement industry accounts for 5% of total carbon dioxide emissions. Concrete is widely used to construct both small and large structures because of its structural versatility, its ability to be molded or cast into almost any desired shape and attractive appearance. Concrete is generally made of ordinary Portland cement (OPC), sand, crushed rock and water. Concrete is a highly durable material, however, the materials used, quality of the mortar, workmanship and the pattern in which the units are assembled can significantly affect the durability of the overall concrete construction. Economy and stability are the primary requisites of any structures. The production of cement, as per reports from about 150 countries, reached 3.7 billion tons in 2012. For every part of cement, we require about six to seven parts of sand and gravel, thus causing deficiency of suitable river sand [11].

Roller-Compacted Concrete (RCC) consists of an engineered mixture of dense-graded aggregates, cement and water. This zero slump concrete mixture, when placed with an asphalt paver and compacted to high density, provides a high-strength, durable pavement structure. RCC uses no forms, requires no conventional finishing, and needs no dowels or reinforcing steel, making it an economical choice. Roller-compacted concrete (RCC) as a paved surface offers facility owners and pavement designers a concrete pavement alternative that may better meet the requirements of specific pavement projects than conventionally cast-in-place concrete pavements. RCC pavement applications can be tailored to the specific needs of a project, particularly those associated with roadway projects within the residential, commercial, and urban roadway sectors [19, 23, 24]. Figures 1a and 1b show typical example of roller compacted concrete pavement construction.

Figures 1a and 1b: Roller compacted concrete pavement construction.

An important benefit of RCC is its cost-effectiveness and ease of construction. RCC pavement essentially mirrors a conventional Portland cement concrete (PCC) pavement in terms of joint spacing and design thickness. However, RCC is engineered and constructed differently than conventional concrete, involving different placement and design considerations even though the concrete mixture is made of the same constituent materials [3-7, 32].

Oyedepo *etal*, (2015) studied the performance of coconut shell ash and palm kernel shell ash as partial replacement for cement in concrete. They concluded that at lower volume of replacement, will enhance the reduction of cement usage in concretes, thereby reducing the production cost and the environmental pollution caused by the dumping of the agricultural waste. Utsev and Taku, (2012) have it that 10% to 15% partial replacement of ordinary Portland cement with coconut shell ash using water-cement ratio of 0.5 are suitable for production of both heavy weight and light weight concrete.

A study [18] concluded that compressive strength was higher than conventional concrete for 5 % and 10% eggshell powder (ESP) replacement at 3, 7 and 28 days of curing ages. ESP replacements greater than 10% had lower strength than conventional concrete. Split tensile strengths of ESP concretes were comparable with conventional concrete up to 15% ESP replacement. However, concrete with 10% and 15% ESP had lower split tensile strength than conventional concrete.

Calcium rich eggshell is a poultry waste with chemical composition nearly same as that of limestone. Use of eggshell waste instead of natural lime to replace cement in concrete can have benefits like minimizing use of cement, conserving natural lime and utilizing waste material. Eggshell waste can be used as fertilizer, animal feed ingredients and other such uses. However, majority of the eggshell waste is deposited as landfills. Eggshell waste in landfills attracts vermin due to attached membrane and causes problems associated with human health and environment. Few investigations were conducted to use eggshell waste in civil engineering applications [10].

Praveen [30] have investigated the combination of Egg shell with silica fumes are used in different combinations to find the feasibility of using Egg shell as an alternate to cement. They concluded that eggshell powder replaces 10%, 20% and 30% in addition with the silica fume by 5%, 10%, and 15% of weight of cement in the M30 concrete. The compressive strength of concrete with eggshell powder increases up to 15 percent without silica fume. Addition of silica fume also enhances the strength but from an economical point of view only the eggshell powder replacement is sufficient enough for getting higher strength. The split

tensile strength of the eggshell powder concrete decreases with the addition of eggshell powder. The flexural strength of the eggshell concrete increases with the addition of eggshell powder up to 15 percent.

Eggshell consists of several mutually growing layers of CaCO_3 , the innermost layer-maxillary 3 layer grows on the outermost egg membrane and creates the base on which the palisade layer constitutes the thickest part of the eggshell. The top layer is a vertical layer covered by the organic cuticle. The eggshell primarily contains calcium, magnesium carbonate (lime) and protein. In many other countries, it is the accepted practice for eggshell to be dried and used as a source of calcium in animal feeds. The quality of lime in eggshell waste is influenced greatly by the extent of exposure to sunlight, raw water and harsh weather conditions. It is the fine grained powder with suitable proportion which is sieved to the required size before use with concrete/mortar. Eggshell powder obtained from industrial wastes is added in various ratios for cement replacement and it was found that replacement of 5% Eggshell powder + 20 % Micro silica can be added without any reduction in compressive strength properties of conventional cement. And replacement of 5% Eggshell powder + 10% Micro silica replacement in cement yields similar flexural strength as in conventional concrete. And replacement of 5% Eggshell powder + 10% Micro silica replacement in cement yields higher Split Tensile strength (all first letters with caps, or none) as compared to other compositions [22].

Kumar *et al*, (2017), concluded that coconut Shell Ash and Eggshell Powder can be formed into useful binding materials. The properties of both wastes are within the range of the values of concrete making cement replacing material (I think it would be better if the phrase were: “the range of values of the concrete making cement replacing material”). The 10% replacement of cement by Coconut Shell Ash and Eggshell Powder has found to be attaining nearer strength as like conventional concrete. [29], had it that partial replacement of cement with 2.5%, 5%, and 15% of Coconut Shell Powder (CSP) and Egg Shell Powder (ESP) in concrete gives an average optimum compressive strength in concrete. The use of Coconut Shell Powder (CSP) and Eggshell Powder (ESP) as a partial replacement of cement produced a cheaper structural light weight concrete using the optimum compressive strength value and lower volume of replacement, will enhance the reduction of cement usage in concretes, thereby reducing the production cost and the environmental pollution caused by the dumping of the agricultural waste. The flexural strength of the eggshell concrete increases with the addition of eggshell powder up to 15 percent.

The cost of cement used in concrete works is on the increase and unaffordable, yet the need for concrete infrastructure and other constructions requiring this material keeps growing with increasing population, thus the need to find alternative binding materials that can be used solely or in partial replacement of cement. Agricultural waste material, in this case, coconut and eggshell. Coconut shell and eggshell are normally disposed at dumpsites/landfills without any commercial return, and the production of these wastes is causing environmental problems. However, dumping issues of these wastes and environmental sustainability can be ensured by proper utilization or recycling of these materials. Through public concern and research efforts, these agro wastes by product materials have potential to be utilized as construction material to replace conventional hydraulic cement in concrete to reduce the cost of construction and reduce environmental hazard. These objectives justified the need for this research.

2. METHODOLOGY

2.1 Materials

2.1.1 Cementitious materials

The type, quality, and quantity of cementitious materials in the mix significantly affect the RCC strength and quality. Roller compacted concrete mixtures can be made with any of the basic types of hydraulic cement, blended cements, or a combination of hydraulic cement and pozzolan. The use of pozzolan is common in RCC projects and, when substituted for a portion of the cement, generally provides for reduced cost and lowered heat generation. Class F fly ash is the most commonly used pozzolan in RCC.

Natural Resources Conservation Service (NRCS) Construction Specification 36—Roller Compacted Concrete, requires that pozzolan be used as part of the cementitious materials in the RCC mix [26]. A detailed discussion of the selection and use of hydraulic cements and supplementary cementitious materials can be found in [1], Guide to the Selection and Use of Hydraulic Cements, and Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual [20, 21]. Supplementary cementitious materials (SCM) can also be used to provide additional fine material and ensure adequate compaction, particularly in mixtures containing standard graded concrete fine aggregate.

2.1.2 Aggregates

Well graded river sand passing through sieve 4.75mm but retained in sieve 2.36mm, 1.18mm, 600 micron, 300 micron and 150 micron was used as fine aggregate used for this study. Crushed granites passing through sieve 31.5mm but retained in sieves 25mm, 18.75mm, 16.0mm, 12.5mm, 9.5mm, 6.25mm and 4.75mm was used as natural coarse aggregate (NCA). The natural coarse aggregate (NCA) and the fine aggregate were selected in accordance with the specifications of [2, 14, 21, 31-34].

2.2 Methods

2.2.1 Chemical analysis of supplementary cementitious materials

The chemical component determinations and the limits placed on each do not predict the performance of a fly ash or natural pozzolan with hydraulic cement in concrete, but collectively help describe composition and uniformity of the material [37-39]. The chemical analysis of supplementary cementitious materials used in this study were conducted in line with the provisions of ASTM C311 / C311M - 18 (2018), Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete.

2.2.2 Concrete mix proportioning

To develop a mixture with the greatest density and strength at the lowest cement content, the designer has some choice in optimizing a mixture for a given project. The mixture design procedures involve selection of well-graded aggregates and cement content (as a percentage of total weight). The concrete mix proportion used in this study is as shown in Table 1.

The concrete specimens were batched and cured in line with the specifications of [2, 3, 26, 7, 9, 16, 17, 20, 21, 27, 31-34]. Concrete mix proportion of 1: 3: 2.5 by weight of cementitious materials, fine aggregate and coarse aggregate as shown in Table 1 was used for all the concrete specimens. The portable water used for batching and curing the concrete specimens satisfied the specification of [16].

Table 1: Measuring and mixing proportions for the concrete specimens at 1:3:2.5 mix ratio.

Concrete specimen mark	Percentage replacement of cement with SDA and ESP (%)	Water-cementitious materials ratio	Cementitious materials (Kg/m ³)			Fine aggregate (Kg/m ³)	Coarse aggregate (Kg/m ³)
			Cement	Coconut shell ash (CSA)	Egg shell powder (ESP)		
CS-ES1	0	0.45	369.2	0.00	0.00	1108	923
CS-ES2	5	0.45	350.74	9.23	9.23	1108	923
CS-ES3	10	0.45	254.16	18.46	18.46	1108	923
CS-ES4	15	0.45	313.82	27.69	23.69	1108	923
CS-ES5	20	0.45	295.36	36.92	36.92	1108	923

2.2.3. Aggregate properties

Sieve analysis, specific gravity and water absorption were conducted for fine aggregate, and coarse aggregate in accordance with the specifications of ASTM D448 (2012). The aggregate impact value (AIV) test, aggregate crushing value (ACV) test and Los Angeles abrasion value test were conducted for the coarse aggregate in line with the specified procedures in [2, 14, 21, 31-34].

2.2.4 Concrete properties

The slump values of all the fresh concrete mixtures were evaluated immediately after batching. The compressive strength values of the concrete were evaluated on the 3rd, 7th, 14th, 28th, and 56th days of age. The splitting tensile strength and the flexural strength values were evaluated at the 14th and 28th day age. The specimens used for the compressive strength and splitting tensile strength tests were cylindrical in shape and measured 150mm diameter and 300mm long. The beam specimens used for the flexural strength test measured 150mm width, 150mm depth and 700mm long. A depth to effective span ratio of 4 was maintained during the flexural test. The slump, compressive strength, splitting strength and flexural strength tests were carried out in line with the procedures specified in [2, 3, 7-9, 17, 21, 26, 27, 31-34].

2.2.3: Water absorption and Voids in hardened concrete:

The density, percentage absorption, and percentage voids in hardened concrete made from coarse aggregate of different shape and texture were determined in accordance with the procedure specified in [15, 28] at the 28th day and 91st day of curing. The specimens used were 100mm diameter and 50mm thick cylindrical concrete of volume 393cm³ and oven dry mass as shown in

Tables 6 and 7. Each portion of the specimens was free from observable cracks, fissures, or shattered edges. Equations 1-7 are used to calculate water absorption, voids and densities of hardened concrete.

$$\text{Absorption after immersion (\%)} = \left[\frac{(B-A)}{A} \right] \times 100 \dots\dots\dots (1)$$

$$\text{Absorption after immersion and boiling (\%)} = \left[\frac{(C-A)}{A} \right] \times 100 \dots\dots\dots (2)$$

$$\text{Bulk density, dry (g/cm}^3\text{)} = g_1 = \left[\frac{A}{C-D} \right] \times \rho \dots\dots\dots (3)$$

$$\text{Bulk density after immersion (g/cm}^3\text{)} = \left[\frac{B}{C-D} \right] \times \rho \dots\dots\dots (4)$$

$$\text{Bulk density after immersion and boiling (g/cm}^3\text{)} = \left[\frac{C}{C-D} \right] \times \rho \dots\dots\dots (5)$$

$$\text{Apparent density (g/cm}^3\text{)} = g_2 = \left[\frac{A}{A-D} \right] \times \rho \dots\dots\dots (6)$$

$$\text{Volume of permeable pore space or voids, (\%)} = \left[\frac{g_2 - g_1}{g_2} \right] \times 100 \text{ or } \left[\frac{(C-A)}{(C-D)} \right] \times 100 \dots\dots\dots (7)$$

Where,

Volume of concrete sample (cm³) = V

Mass of oven dry sample in air (g) = A

Mass of surface-dry sample in air after immersion (g) = B

Mass of surface-dry sample in air after immersion and boiling (g) = C

Apparent mass of sample in water after immersion and boiling (g) = D

Density of water (g/cm³) = $\rho = 1$

3. RESULTS AND DISCUSSION

3.1 Aggregates characteristics

The average results of the sample 1 and sample 2 gradation/sieve analysis of fine aggregate, coarse aggregate and combine aggregate are shown in Figures 2, 3a and 3b respectively with fine modulus of 3.68. The results of the physical and mechanical properties of the coarse aggregate, and fine aggregate are shown in Table 2. The fine and coarse aggregate properties conform to specifications of [2, 8, 14, 21, 31-34].

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Figure 2: Sieve analysis curve of fine aggregate (average of samples 1 and 2)

Figure 3a: Sieve analysis curve of coarse aggregate (average of samples 1 and 2)

Figure 3b: Sieve analysis curve of combine aggregate (average of samples 1 and 2)

Table 2: Physical and mechanical properties of the aggregate used

Aggregate	Specific gravity	Water absorption (%)	Aggregate crushing value (%)	Aggregate impact value (%)	Los Angeles abrasion value (%)
Fine	2.633	1.434	-	-	-
Natural Coarse (crushed granite)	2.731	1.23	19.63	22.54	24.71

3.2 Characteristics of supplementary cementitious materials

Table 3 shows the chemical composition of coconut shell Ash (CSA) and eggshell powder (ESP) used in this study. The hydraulic cement used in this study conforms to the specifications of [1, 2, 12, 20, 21,]. The eggshell powder was prepared in line with the specifications of [13] and the saw dust ash conform to the specification of [13, 20] for Class F fly ash and are in agreement with the findings of [39]. According to [4, 13, 20, 26], class F fly ash is defined as having a sum of the oxides ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) equal or greater than 70% and Class C fly ash as having the sum of the oxides ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) equal or greater than 50%.

Pozzolans are silicate-based materials that react with (consume) the calcium hydroxide generated by hydrating cement to form additional cementitious materials.

Why is consuming calcium hydroxide a good thing? Calcium hydroxide (lime) accounts for up to 25% of the hydrated Portland cement, and lime does not contribute to the concrete's strength or durability. Pozzolans combine with the lime to produce additional calcium silicate hydrate, the material responsible for holding concrete together. By consuming the excess lime, the strength of the concrete is increased, its density is increased, efflorescence is decreased, and the propensity for alkali-silica reaction (reaction with glass) is decreased, or even virtually eliminated.

Typically, pozzolans such as eggshell powder and coconut shell ash are used as cement *replacements* rather than cement *additions*. Adding pozzolans to an existing concrete mix without removing an equivalent amount of cement increases the paste content and decreases the water/cement ratio. In other words, adding more pozzolans to a mix changes the mix proportions. Replacing some of the cement with pozzolans preserves the mix proportions. **Pozzolans replace cement pound for pound.** Depending upon the particle size, chemical composition and dosage, different pozzolans will affect the concrete strength differently and at different times during curing. Most pozzolans are used

individually, but blends of two or more different pozzolans can be used to take advantage of the characteristics each pozzolan offers. Typical examples are fly ash and silica fume blends, and the materials used in this study, where the fly ash increases workability and particle packing and the silica fume helps with early strength and total strength development [37-39].

Table 3: Chemical composition of eggshell powder (ESP) and coconut shell ash (CSA).

S/N	Oxides	ESP (%)	CSA (%)
1.	SiO ₂	0.08	37.97
2.	Al ₂ O ₃	0.03	24.12
3.	Fe ₂ O ₃	0.02	15.48
4.	CaO	52.1	4.98
5.	MgO	0.01	1.89
6.	Na ₂ O	0.15	0.81
7.	K ₂ O	-	0.95
8.	SO ₃	0.62	0.83
9.	LOI	42.2	11.94
10.	Others	4.79	1.03

3.3 Concrete characteristics

Table 4 shows the densities and compressive strength values of concrete at different percentage replacement of cement with a mixture of coconut shell ash and eggshell powder. The densities values for different percentage replacement of cement with mixture of coconut shell ash and eggshell powder increase with increase in percentage replacement of cement. This is due to increase in fine due to addition of supplementary cementitious materials. There is no significant change in later values of the compressive strength of concrete containing 0% to 20% replacement of cement with a mixture of coconut shell ash and eggshell powder as shown in Table 4 and Figures 4 and 5. Concrete specimens containing coconut shell ash and eggshell powder mixture show increase in splitting tensile strength and flexural strength values as shown in Figures 6 and 7.

The compressive strength of RCC is comparable to that of conventional concrete, typically ranging from 28 kg/m³ to 41 kg/m³. Some projects have reached compressive strengths higher than 48 kg/m³, however, practical construction and cost considerations would likely specify increased thickness rather than strengths of this nature [23-25, 31, 33]. The densely graded aggregates used in RCC mixtures help the concrete achieve high levels of compressive strength as shown in Table 4 and Figure 4 and 5. The low w/cm of RCC mixtures

produces a low-porosity cement matrix that also contributes to the high compressive strength of the concrete. The compressive strength results of 0% to 20% replacement of cement with a mixture of coconut shell ash and eggshell powder satisfied the minimum 28 days strength of 31N/mm² to 41N/mm² and 35N/mm² to 41N/mm² for standard and high-performance roller compacted concrete pavement and roller compacted parking lots as specified in [2, 3, 5-7, 9, 17, 21, 26, 27, 31-34].

Table 4: Average Compressive Strength Test Results (f_{ck}).

Cube mark	Percentage replacement of cement (%)	Slump (mm)	Density (Kg/m ³)	3 rd day N/mm ²	7 th day (N/mm ²)	14 th day (N/mm ²)	28 th day (N/mm ²)	56 th day (N/mm ²)	91 st day (N/mm ²)
CS-ES1	0	3.0	2426	20.10	25.00	33.58	43.21	47.81	56.44
CS-ES2	5	4.2	2431	18.20	22.66	31.08	43.02	48.61	58.32
CS-ES3	10	4.4	2440	17.43	21.11	30.11	42.08	46.32	57.11
CS-ES4	15	4.9	2445	14.40	19.03	29.60	40.37	43.86	54.23
CS-ES5	20	5.6	2448	11.89	17.23	28.20	37.11	41.33	51.11

Figure 4: Relationship between the compressive strength (N/mm²) and Curing age (days).

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Figure 5: Relationship between the compressive strength (N/mm²) and Curing age (days).

Figure 6: Relationship of the 14th and 28th days splitting tensile strength with percentage replacement of cement with SDA and ESP.

Figure 7: Relationship of the 14th and 28th days flexural with percentage replacement of cement with SDA and ESP.

3.4: Water absorption and Voids in hardened concrete (durability tests):

The specimen used for the Water absorption and Volume of permeable pore space (voids) in hardened concrete at 28th and 91st day curing age satisfied the specifications of [15, 28]. From Tables 5 and 6 and Figures 8 and 9 it can be observed that water absorption after immersion, water absorption after immersion and boiling and volume of permeable pore space (voids) and the volume of permeable pore spaces decrease with increase in age and with increase in percentage replacement of cement with coconut shell ash (CSA) and eggshell powder (ESP). The concrete made with 10% to 20% replacement of cement with CSA and ESP show low water absorption and low volume of permeable pore spaces (voids). This indicates reliable durability qualities. Permeability of the concrete in a Portland cement concrete pavement is a major factor for long-term durability. Pavements with low permeability resist penetration of moisture into the concrete matrix, leading to long-term durability.

Figure 8: Water absorption after immersion in hardened concrete at 28th and 91st days curing age (%)

Table 5: Water absorption and Volume of permeable pore space (voids) in hardened concrete at 28th day.

S/N	Description and units	Percentage replacement of cement with coconut shell ash and eggshell powder.				
		0%	5%	10%	15%	20%
1.	Volume of sample (cm ³)	393	393	393	393	393
2.	Mass of oven dry sample in air (g)	947	956	963	968	968
3.	Mass of surface-dry sample in air after immersion (g)	979	983	984	984	984
4.	Mass of surface-dry sample in air after immersion and boiling (g)	985	986	992	989	989
5.	Apparent mass of sample in water after immersion and boiling (g)	592	593	599	596	596
6.	Absorption after immersion (%)	3.38	2.82	2.22	1.65	1.65
7.	Absorption after immersion and boiling (%)	4.01	3.14	3.01	2.17	2.17
8.	Density of water (g/cm ³)	-	-	-	-	-
9.	Bulk density, dry (g/cm ³)	2.41	2.43	2.45	2.46	2.46
10.	Bulk density after immersion (g/cm ³)	2.49	2.50	2.50	2.50	2.50
11.	Bulk density after immersion and boiling (g/cm ³)	2.51	2.51	2.52	2.52	2.52
12.	Apparent density (g/cm ³)	2.67	2.63	2.65	2.60	2.60
13.	Volume of permeable pore space or voids, (%)	9.74	7.61	7.55	5.39	5.39

Figure 9: Volume of permeable pore spaces (voids) in hardened concrete at 28th and 91st days curing age

Table 6: Water absorption and Volume of permeable pore space (voids) in hardened concrete at 91st day.

S/N	Description and units	Concrete specimens containing coarse aggregate of different shape and texture.				
		0%	5%	10%	15%	20%
1.	Volume of sample (cm ³)	393	393	393	393	393
2.	Mass of oven dry sample in air (g)	947	956	963	968	968
3.	Mass of surface-dry sample in air after immersion (g)	969	974	977	975	975
4.	Mass of surface-dry sample in air after immersion and boiling (g)	973	977	981	980	980
5.	Apparent mass of sample in water after immersion and boiling (g)	580	584	588	587	587
6.	Absorption after immersion (%)	2.32	1.88	1.45	0.72	0.72
7.	Absorption after immersion and boiling (%)	2.75	2.2	1.87	1.24	1.24
8.	Density of water (g/cm ³)	-	-	-	-	-
9.	Bulk density, dry (g/cm ³)	2.41	2.43	2.45	2.46	2.46
10.	Bulk density after immersion (g/cm ³)	2.47	2.48	2.49	2.48	2.48
11.	Bulk density after immersion and boiling (g/cm ³)	2.48	2.49	2.5	2.49	2.49
12.	Apparent density (g/cm ³)	2.58	2.57	2.57	2.54	2.54
13.	Volume of permeable pore space or voids, (%)	6.6	5.5	4.67	3.15	3.15

4. CONCLUSION

The following conclusions were drawn at the end of this study.

- i. A mixture of coconut shell ash and eggshell powder gives good pozzolan and cementitious material and can be used as Supplementary Cementitious Materials in Roller Compacted Industrial Plant Access Roads and Parking Lots.
- ii. The use of coconut shell ash and eggshell powder as supplementary cementitious material should be encouraged. This leads to cost effective and environmentally friendly construction. It also leads to savings in the quantity of cement that would have been consumed and as such the sustainability of the cement industry can be guaranteed.
- iii. The concrete batching and mixing proportion of 1: 4: 3.5 of cementitious materials, fine aggregate and coarse aggregate used in this study gives a cement content at the range of 282.4kg/m³ to 225.92kg/m³ for 0% to 20% replacement of cement with a mixture of coconut shell ash and eggshell powder. This satisfies the minimum cement content of 148.32kg/m³ (250lb/yd³) and the minimum cementitious material

content of 267kg/m^3 (450lb/yd^3) specified in [2-9,17, 26, 27, 31-34] for roller compacted concrete pavements and parking lots on ground.

- iv. Using a mixing ratio and proportion specified by relevant standards, concrete mixtures containing up to 20% coconut shell ash and eggshell powder exhibit similar characteristics compared to non-coconut shell ash and eggshell concrete.
- v. Compressive strength increases with increase in curing age irrespective of the percentage of coconut shell ash and eggshell powder.
- vi. Better mechanical and physical properties of concrete can be obtained with the replacement of cement with a mixture of coconut shell ash and eggshell powder.
- vii. The compressive strength results showed that, up to 20% replacement of cement with coconut shell ash and eggshell powder satisfied the minimum 28 days compressive strength requirement of 31N/mm^2 to 41N/mm^2 and 35N/mm^2 to 41N/mm^2 for standard and high-performance roller compacted industrial plant access roads and parking lots.
- viii. Roller compacted concrete is an appropriate pavement material for container facilities, parking lots and industrial access roads based on the high strength and low cost of construction, and the good functional performance over many years of operation.
- ix. The low maintenance costs and versatility of the concrete pavement continue to make RCC pavements an important design choice.

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