

# Assessing the Performance of Recycled Glass Pozzolana on Properties of Concrete with Palm Kernel Shell as Partial Replacement of Coarse Aggregate

Christopher K. Dzivenu <sup>a</sup>, Vincent K. Akortia <sup>b\*</sup>, Charles K. Kankam <sup>a</sup>  
and John K. Quarm Junior <sup>c</sup>

<sup>a</sup> Department of Civil Engineering, KNUST, Kumasi, Ghana.

<sup>b</sup> Works Department, Ho West District Assembly, Dzolokuipa, Ghana.

<sup>c</sup> Physical Works and Development, UCC, Cape Coast, Ghana.

## **Authors' contributions**

*This work was carried in collaboration between all four authors. All the authors read and approved the final manuscript.*

## **Article Information**

### **Open Peer Review History:**

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/92254>

**Original Research Article**

**Received 20 July 2022**  
**Accepted 26 September 2022**  
**Published 07 October 2022**

## **ABSTRACT**

The cost of concrete products keeps increasing due to the increasing cost of cement and crushed granite stone as they are the most commonly used binding agent and aggregate in Ghana. Hence, there is the need to exploit properties of glass powder as pozzolana in concrete and palm kernel shell as alternative aggregates to reduce cost and effect of waste they generate on the environment. This study investigated the potential use of recycled glass as pozzolana in ordinary Portland cement concrete and palm kernel shell as partial replacement for aggregate; specifically looked at particle size distribution, optimum percentages of glass powder pozzolana needed and physical/mechanical properties of concrete with 25% palm kernel shell and varying percentages (0% to 25%) of recycled glass powder as partial replacement of coarse aggregate and cement respectively. Laboratory experimental methods were used to investigate the properties of grade C25 mix design concrete. The concrete cubes cast were cured in water for 28 days. Tests included density, fresh concrete workability, water absorption and compressive strength. The results indicated that the maximum compressive strength of concrete occurred around 15% recycled glass powder replacement and then reduced thereafter. There was increased workability of concrete with

\*Corresponding author: Email: akovin4@yahoo.co.uk;

increased percentage of recycled glass powder and the slump for 5% - 25% recycled glass powder replacement was higher than the control mix (MC). The use of glass powder as pozzolana in concrete can therefore be encouraged to reduce the generation of glass waste which causes environmental nuisance; however, its usage should not exceed 15% cement replacement.

**Keywords:** Recycled glass powder; pozzolana; palm kernel shell; concrete; compressive strength.

## 1. INTRODUCTION

The cost of concrete products keeps increasing due to the frequent increase in the price of Portland cement as it is the most used concrete binding agent in Ghana. Cement manufacturing is a high energy-intensive venture. To start with, energy is utilized as fuel to fire the rotational kilns to deliver the cement clinker. Secondly, electrical energy is used in operating the various units—specifically raw material and cement grinding systems. Currently, electrical energy consumption in cement production alone makes up approximately 12 - 15% of the total energy consumption with the attendance high energy cost of fuel and electricity. About 118kWh is estimated as the amount of electrical energy consumed per ton of cement production [1]. There is, therefore, the need to find alternatives to further reduce its cost and augment its usage. Also, another factor affecting the cost of concrete is the over-reliance on crushed granite chippings as aggregate. There is also the need to curb the amount of energy used in its production. Palm kernel shell (PKS) can also be used as aggregates in concrete. Research has shown that palm kernel shells can be utilized as aggregates in concrete [2-6]. Falade [7] also researched the supportability of palm kernel shells that could be used as aggregates in light and dense concrete for structural and non-structural purposes. He concluded that palm kernel shells could be used as an aggregate for up to 45% in the production of light and dense concrete. Meanwhile the shells end up as waste after the nuts are removed from them. Much research has been carried out to find alternative binding agents and materials other than ordinary Portland cement and normal coarse aggregate in the construction industry. Recently, Kumar and Chaudhary [8] found that the workability of concrete made utilizing waste glass as cement replacement increased with replacement level. With regard to the concrete strength, Nassar and Soroushian [9], Neville [10] and Lalitha, et al. [11] reveal that the decrease in compressive strength can be attributed to the slow pozzolanic response that happens between the reactive silica in the recycled glass powder (RGP) and the

calcium hydroxide produced from the cement hydration. On the contrary, researches have shown that, at the higher age recycled glass concrete (15 to 20% of cement replacement) with grinded waste glass powder gives compressive strengths exceeding that of control concrete [12], which might be due to presence of certain common chemical properties (see Table 1). This means that the previous research measured the concrete strength at much earlier age. However, all these studies were conducted on the two materials – palm kernel shell and recycle glass powder (RGP) - in isolation without combining them to examine their effect.

In Ghana, glass is generally used domestically and in the construction industry. It is used for decorative purposes, packaging of food and drinks, as an insulation material, structural component, and cladding among others. As a result of its wide usage, a lot of waste is also generated causing environmental degradation due to its indiscriminate disposal [13,14]. Therefore, the need to exploit its mechanical and physical properties as pozzolana in concrete mixes with the added aim to reducing the effect of waste generated from the glass on the environment. Hence, this study examined the combined effect of recycled glass powder (pozzolana) and palm kernel shell as possible partial replacement for cement and coarse aggregate respectively, thus workability, density, water absorption and compressive strength of concrete produced.

**Table 1. Chemical compositions of waste glass pozzolans and cement [15]**

Compound	Waste-Glass [9]	Cement (Ryou et al. 2006)
SiO <sub>2</sub>	68	20.3
Al <sub>2</sub> O <sub>3</sub>	7	4.7
Fe <sub>2</sub> O <sub>3</sub>	< 1	3
CaO	11	61.8
MgO	< 1	3.3
K <sub>2</sub> O	< 1	0.6
Na <sub>2</sub> O	12	0.2
SO <sub>3</sub>	-	3.6
LOI	-	-

## 2. EXPERIMENTAL METHODS

### 2.1 Materials

The materials included recycled glass powder (RGP) pozzolana of glass waste from construction sites and local glass selling points in Accra, Ghana and limestone Portland cement grade 42.5R produced by GHACEM, Tema that meets BS EN 197-1:2011 [16] requirements (main binder), crushed granitic stone of nominal size 20mm from a commercial quarry and sand from a mining pit near Accra. The aggregates meet requirements of BS EN12620 [17] and BS EN 196-1 (2005). Also, 25% of palm kernel shell (PKS) was used partially to replace coarse aggregate based on earlier research works conducted [4,18] and clean safe drinking water from Ghana water company that complied with requirements of BS 8680 [19] standard.

#### 2.1.1 Recycled glass powder (RGP) preparation

Glass waste collected from various construction sites and local selling points were crushed into smaller sizes and milled into fine powder with high-speed motor machine. To start grinding the glass, the nozzle of the grinder where the grounded powder came out was tied with rubber bag and sack to reduce dust that came out during grinding (Fig. 1a, b & c).

##### 2.1.1.1 Physical properties of RGP

###### 2.1.1.1.1 Specific gravity

The density bottles were used to determine the specific gravity of the RGP in accordance with BS 812-2:1995. Sieve 425 micron was used to

sieve the RGP and 10grammes of RGP passing through the sieve was weighed (Fig. 2a). The bottles were wiped and dried, after which the weight of the empty bottle (M1) was taken (Fig. 2b). The weight of the empty bottle plus the weight of 10grammes of RGP (M2) was noted. The bottle was filled with distilled water and weight (M4) taken (Fig. 2c). The glass filled with distilled water and RGP and weight (M3) taken (Fig. 2d) placed in a desiccator (Fig. 2e) to allow all entrapped air to be removed. The specific gravity of RGP was computed as

$$(SG) = \frac{(M2-M1)}{(M2-M1)-(M3-M4)} \quad (1)$$

Where: M1 = Weight of empty bottle in gm. M2 = Mass of bottle and RGP in gm.

M3 = Mass of bottle, RGP, and distilled water in gm. M4 = Mass of bottle filled with distilled water in gm.

###### 2.1.1.1.2 Fineness of RGP

Sieve analysis of RGP was performed and retained material on every sieve was weighed to the closest 1 gram in accordance with BS EN 933-1:1997 (Figs. 3a, b).

#### 2.1.2 Fine aggregate

Sieve analysis and silt test were evaluated by the equipment described in the BS EN 933-1:1997 [28].

##### 2.1.2.1 Sieve analysis of the fine aggregate

The fine aggregate was first dried and weighed. The weighed sand was washed to remove all impurities and oven-dried for 24 hours. The oven-dried sand was weighed again and the



(a) Broken glass wastes



(b) Glass waste grinding machine



(c) RGP

Fig. 1. Preparation of RGP



(a) Weighing of recycled glass sample



(b) Weighing of empty density bottle



(c) Weighing of density bottle and water weighed



(d) Weighing of bottle, water and glass powder



(e) Bottle plus recycled glass powder and water placed in desiccator

Fig. 2. Specific gravity of RGP



(a) Recycled glass powder on top sieve arranged according to sizes



(b) Recycled glass powder and sieves mounted on mechanical shaker

Fig. 3. Sieve analysis of RGP

value noted. Sieves of various sizes and pan were cleaned and arranged according to sizes in descending order from top with the pan at the

bottom. The oven-dried sand was placed on the top sieve and placed on the mechanical shaker, held tightly and was allowed to operate



for 5 minutes (Fig. 4a). The retained material on every sieve was weighed to the nearest to 1 gram. Fine aggregate passing through 4.75mm Sieve was utilized for casting all the specimens.

### 2.1.2.2 Silt test on fine aggregate

Silt content tested with a glass cylinder (Fig. 4b) filled with distilled water up to 50ml, the fine aggregate was added to the water in the cylinder until it rose to 100ml and shake vigorously covered. Additional distilled water was added to the cylinder up to 150ml and allowed to stand for 2 hours (Fig. 4c), after which the silt thickness was measured and calculated as

$$\text{Silt content (\%)} = \frac{t \times 100}{T} \quad (2)$$

where  $t$  = silt thickness (mm);  $T$  = total thickness (mm)

### 2.1.3 Coarse aggregate

Materials that retained on sieve 4.75 mm were utilized as coarse aggregates for casting all test specimens. The physical properties of the coarse aggregate, namely, relative density, bulk density, sieve analysis, and water absorption were determined in accordance with standard procedures. The coarse aggregate was sieved through a set of sieves to obtain its grading as per the requirements of BS EN 933-1:1997 [20] (as shown in Fig. 5) and water absorption, bulk density of the coarse aggregate and relative density were tested as per the procedures outlined within the BS 812: Part 2: 1995 and BS EN 1097-part 3:1998 [21,22].



(a) Fine aggregate and sieves mounted on mechanical shaker



(b) Glass cylinder



(c) Cylinder allowed to stand for 2 hours

Fig. 4. Sieve analysis and Silt test on fine aggregate



(a) Fine aggregate and sieves mounted on mechanical shaker  
Coarse aggregate and sieves mounted on shaker

Fig. 5. Sieve analysis on coarse aggregate

**2.1.3.1 Water absorption and Specific gravity of coarse aggregate**

A sample of coarse aggregates was taken and washed off all impurities. The sample was transferred into a tray and filled with water and allowed to completely immerse and following BS 812: Part 2: 1995 [21] (Fig. 6a, b, c). It was then oven dried at 105°C for 24hours and weighed after air cooling at room temperature (M4). Relative density and water absorption were computed as follows:

$$\text{Relative density on an oven-dried basis} = \frac{M_4}{M_1 - (M_2 - M_3)} \quad (3)$$

$$\text{Relative density on a saturated surface dry basis} = \frac{M_1}{M_1 - (M_2 - M_3)} \quad (4)$$

$$\text{Apparent relative density} = \frac{M_4}{M_4 - (M_2 - M_3)} \quad (5)$$

$$\text{Water absorption (\% of dry mass)} = \frac{100(M_1 - M_4)}{M_4} \quad (6)$$

Where: M1 is the mass of saturated surface dry coarse aggregate in the air in grams.  
M2 is the mass of pycnometer + water + coarse aggregate in grams.

M3 is the mass of pycnometer + water in grams  
M4 is the mass of oven-dried coarse aggregate in grams

**2.1.3.2 Bulk density of coarse aggregate**

The bulk density of the coarse aggregate was determined in two stages consistent with the requirements of BS EN 1097-3:1998 (Fig. 7). The loose bulk and compacted bulk densities were computed as follows:

$$\rho = \frac{M}{V} \quad (7)$$

where:  $\rho$  = Bulk density of loose or compacted coarse aggregate in kg/m<sup>3</sup>; M= Mass in kg; V = volume in m<sup>3</sup>.

**2.1.4 Palm kernel shell (pks)**

**2.1.4.1 Sieve analysis, Specific gravity and water absorption of PKS**

These properties of PKS as partial replacement for the coarse granitic stones followed the same steps in finding same for the major coarse aggregate above. The sample of the PKS used is shown in Fig. 8.



**Fig. 6. Determination of water absorption and specific gravity of coarse aggregate**



**(a) Cylindrical steel container**



**(b) Cylindrical steel container filled with loose coarse aggregate**



**(c) Weighing of coarse aggregate**



(d) Tamping rod permitted to fall easily from a height of 50mm above the surface of the aggregate

Fig. 7. Bulk density of coarse aggregate



(a) Sample of palm kernel shell



(b) Palm kernel shell and sieves mounted on shaker

Fig. 8. Sample of PKS

Table 2. Mix proportion of concrete used

Specimen ID	Mix proportion (ratio)				
	Cement	RGP	Fine aggregate	Coarse aggregate	PKS
MC	1	0	2	4	0
$M_{pks}$	1	0	2	3	1
$M_{(25,5)}$	0.95	0.05	2	3	1
$M_{(25,10)}$	0.9	0.1	2	3	1
$M_{(25,15)}$	0.85	0.15	2	3	1
$M_{(25,20)}$	0.8	0.2	2	3	1
$M_{(25,25)}$	0.75	0.25	2	3	1

Where: MC = Normal concrete mix without RGP and PKS;  $M_{pks}$  = Concrete mix with only 25% PKS replacement of coarse aggregate;  $M_{(25,5)}$  = Concrete mix with 25% PKS replacement of coarse aggregate and 5% RGP replacement of cement;  $M_{(25,10)}$  = Concrete mix with 25% PKS replacement of coarse aggregate and 10% RGP replacement of cement and  $M_{(25,15)}$  = Concrete mix with 25% PKS replacement of coarse aggregate and 15% RGP replacement of cement; in that order

## 2.2 Concrete Mix Design

The mix design was based on the American Concrete Institute Committee 211.1 (1991) method to determine various proportions of materials. A trial mix for C25 was adopted for the experiment with control mix ratio of 1:2:4

(cement: fine aggregate: coarse aggregate) and water-cement ratio of 0.6. Portland limestone cement was partially replaced for 0%, 5%, 10%, 15%, 20% and 25% with recycled glass powder by volume while coarse aggregate was replaced partially with 25% PKS by volume as shown in Tables 2 and 3.





**(a) Fine aggregate on mixing platform**



**(b) Cement and recycled glass powder added to fine**



**(c) Mixture of cement, recycled glass powder and fine aggregate**



**(d) Coarse aggregate and shells of palm kernel added to the mixture of cement, recycled glass powder and fine aggregate**



**(e) Mixture of fine aggregate, cement, recycled glass powder, coarse aggregate and shells of palm kernel**



**(f) Water added to the mixture of fine aggregate, cement, recycled glass powder, coarse aggregate and shells of palm kernel**



**(g) Mixed concrete**

**Fig. 9. Mixing of concrete**



**Table 3. Percentage replacement of cement and coarse aggregate used**

Specimen ID	% replacement of cement and coarse aggregate				
	Cement (%)	RGP (%)	Fine aggregate (%)	Coarse aggregate (%)	PKS (%)
MC	100	0	100	100	0
M <sub>pk<sub>s</sub></sub>	100	0	100	75	25
M <sub>(25,5)</sub>	95	5	100	75	25
M <sub>(25,10)</sub>	90	10	100	75	25
M <sub>(25,15)</sub>	85	15	100	75	25
M <sub>(25,20)</sub>	80	20	100	75	25
M <sub>(25,25)</sub>	75	25	100	75	25

Where: MC = Normal concrete mix without RGP and PKS; M<sub>pk<sub>s</sub></sub> = Concrete mix with only 25% PKS replacement of coarse aggregate; M<sub>(25,5)</sub> = Concrete mix with 25% PKS replacement of coarse aggregate and 5% RGP replacement of cement; M<sub>(25,10)</sub> = Concrete mix with 25% PKS replacement of coarse aggregate and 10% RGP replacement of cement and M<sub>(25,15)</sub> = Concrete mix with 25% PKS replacement of coarse aggregate and 15% RGP replacement of cement; in that order



(a) Compacting of concrete sample in slump mold



(b) Slump measurement

**Fig. 10. Slump test**



(a) Cast specimens



(b) Curing of specimens

**Fig. 11. Casting and curing of concrete specimens**

All the stages involved in the mixing of the various concrete materials into the final concrete test specimens are illustrated in Fig. 9.

### 2.2.1 Slump test

Samples from the freshly mixed concrete for every RGP and PKS replacement were taken for

a slump test as described in BS EN 12350-2:2000 [23] to determine consistency and workability before test specimens were cast to satisfy 50-80mm slump per the code condition. A frustum of cone with internal dimensions of 200mm base diameter, 100 mm top diameter and 300mm high was used as indicated in Fig. 10.

### 2.2.2 Casting of cubes

Test specimens of cubes were casted in rigid wooden molds made of marine plywood measuring 150mm × 150mm × 150mm internally with BS EN 12390-2 [24] requirement. Altogether, forty-nine (49) cubes were casted: seven (7) for each percentage replacement for each mix and accordingly labeled. They were immersed in fresh water for curing after 24 hours until the day of testing (Fig. 11).

## 3. TESTING OF SPECIMENS

### 3.1 Compressive Strength of Cubes

Compressive strength test was carried out in accordance with BS EN 12390-3:2002 [25]. A set of three cubes each were tested for the same age (7days and 28 days). The cubes were removed from the water on the testing day and were covered in a sack and transported to the laboratory for testing. At the laboratory the cubes dimensions and weight were taken and recorded (Fig. 12a); the bearing surfaces of the testing machine and specimens were cleaned. The test cube was placed within the machine such that the load was applied to the reverse sides of the cube as cast (Fig. 12b). The cube was aligned centrally on the bottom of the machine. The load was applied gradually until the cubes failed and the maximum applied load was noted (Fig. 13c).

The average compressive strength of three cubes was taken for the compressive strength for a concrete mix and age.

The compressive strength was calculated as:

$$\sigma = \frac{P}{A} \quad (8)$$

Where,  $\sigma$  = Compressive strength (N/mm<sup>2</sup>); P = Maximum load a cube sustained (N); A = cross-sectional Area of a cube (mm<sup>2</sup>).

The result of compressive strength testing was reported as an average of 3 specimens for the 7<sup>th</sup> and 28<sup>th</sup> days strength for each concrete mix in N/mm<sup>2</sup>.

### 3.2 Density of Concrete

Concrete density is one of the most important properties of concrete, as it controls a very significant role in the determination of the dead weight of a structure. In testing cubes for compressive strength, the mass of all samples were taken and recorded according to each replacement mix. The density of concrete was computed with reference to BS EN 12390-7:2000 [26] using Eq. 7 above.

### 3.3 Water Absorption of Concrete

The pore structure of concrete contributes massively to the rate of water absorption of concrete. It is also a factor that affects the durability of concrete. Water absorption of concrete was evaluated at 28 days for each mix as per BS 1881-122:2011 [27]. One sample each of the cast cube was tested for water absorption, the sample was removed from the water after 28 days and weighed (A). The sample was oven dried for 24 hours and weighed again (B). Water absorption of concrete was computed using the following formula:

$$\text{Water absorption (\%)} = \frac{A-B}{B} \times 100 \quad (9)$$



(a) Weighing of cubes



(b) Concrete cube well positioned in the machine



(c) Load applied gradually to the cube

Fig. 12. Testing of cubes

Where: A = Mass of the surface-dry specimen after exposure in the air (g); B = Oven-Dried mass of specimen in the air (g)

The results of water absorption test in percentages were reported for 28 days old specimens after the preliminary curing of 28 days for each concrete mix.

#### 4. RESULTS AND DISCUSSION

##### 4.1 General

This section presents and discusses results of experimental tests of this study. The physical tests of recycled glass powder (RGP), fine aggregate, coarse aggregate, and palm kernel shell (PKS) are reported. The physical tests conducted on the materials included fineness, specific gravity, particle size distribution, water absorption, bulk density and silt content in the

sand. A mix design of grade C25 concrete with a batching ratio 1:2:4 was employed for normal mix concrete as control (MC). The coarse aggregate was partially replaced with 25% PKS while cement was partially replaced with RGP at 5%, 10%, 15%, 20% and 25% rates. Workability, density, compressive strength and water absorption tests of concrete produced were conducted as means of evaluating the effect of RGP partial replacements.

##### 4.2 Properties of Materials

Table 4 indicates the results of the experiment about some physical properties of the materials as described. For instance, specific gravity of coarse aggregate used was 2.6 and that of palm kernel shell (PKS) was 1.33 while recycle glass powder (RGP) had 2.58. Again, while the rate of water absorption was 0.17% for coarse aggregate, it was 8.6% for PKS depicting their kind.

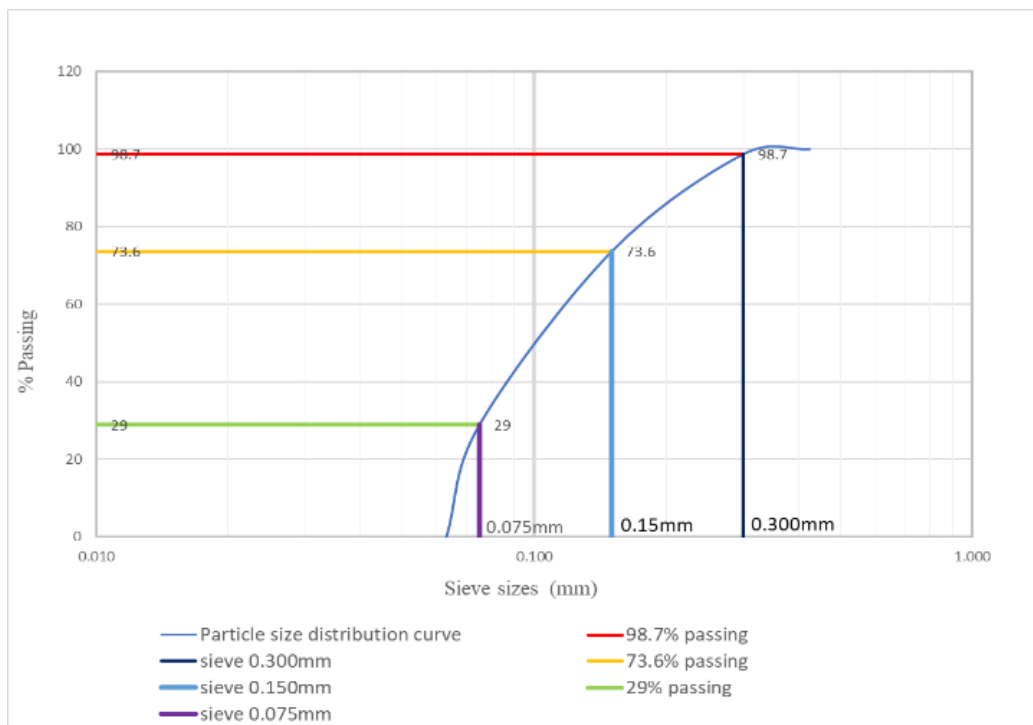
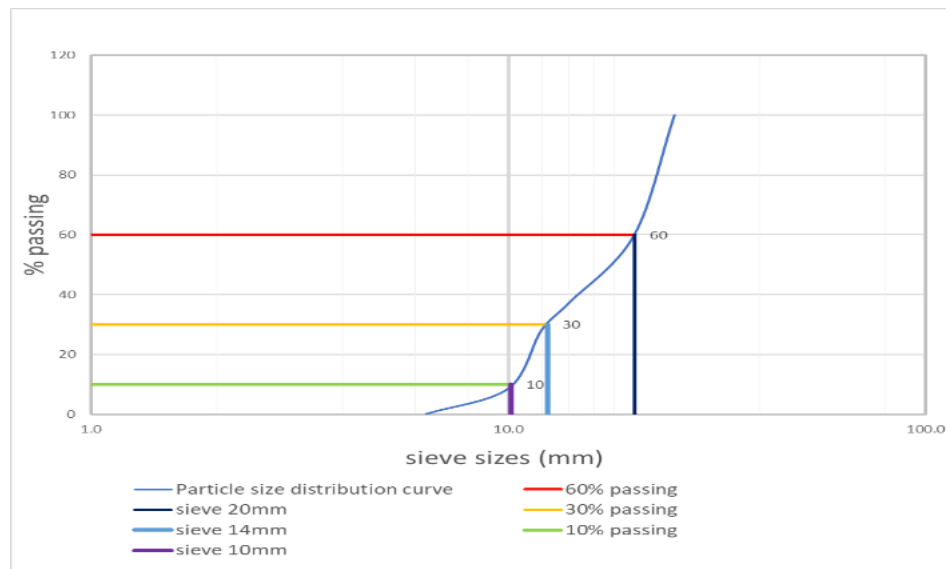


Fig. 13. Particle size distribution of RGP

Table 4. Physical properties of aggregates

Physical property	Coarse aggregate	PKS	RGP	Fine aggregate
Specific Gravity	2.6	1.33	2.58	-
Water absorption (%)	0.17	8.6	-	-
Bulk density (Loose) (kg/m <sup>3</sup> )	1408.76	558.87	-	-
Bulk density (Compacted) (kg/m <sup>3</sup> )	1635.86	664.69	-	-
Silt test (%)	-	-	-	6.06



**Fig. 14. Particle size distribution of coarse aggregate**

#### 4.2.1 Grading of materials

##### 4.2.1.1 RGP (Fineness)

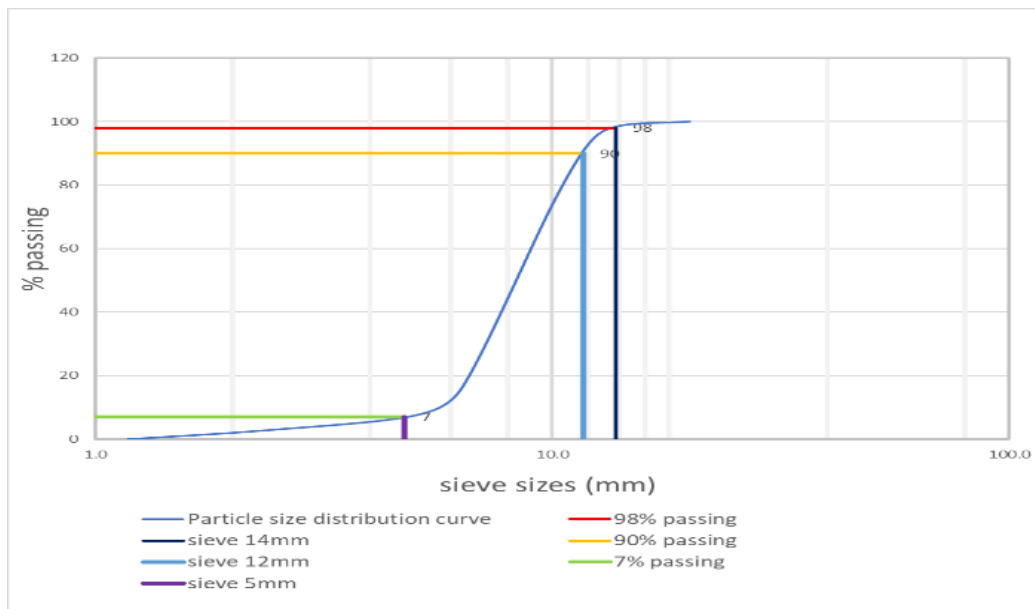
The sieve analysis displayed in Fig. 13 shows that 98.7% of the RGP passed through sieve size of 300 $\mu$ m, while 73.6% passed through sieve 150 $\mu$ m and 29% through sieve 75 $\mu$ m. The result proves that the RGP used for this study met the pozzolanic physical property in line with the finding of Shi et al. [15] that the pozzolanic properties of glass are first notable at particle sizes below approximately 300 $\mu$ m; and, that below 100 $\mu$ m, glass can have a pozzolanic reactivity which is more than that of fly ash at low percent cement replacement levels and after 90 days of curing.

Similarly, the particle size distribution from sieve analysis conducted on coarse aggregate shows that the grading of aggregate falls within the appropriate limits of the requirement of the BS 882: 1992, results of the sieve analysis is shown in Fig. 14. Also, the particle size distribution of PKS in Fig. 15 shows that 98% of PKS passed through sieve of 14mm, while 90% passed through sieve 12mm and 7% through sieve 5mm. This distribution of particles falls within the appropriate limits of the requirement of the BS 882: 1992. Finally, the particle size distribution from sieve analysis conducted on fine aggregate (clean and dry pit sand) displayed in Fig. 16 shows the grading falls within the appropriate limits of the requirement of the BS 882: 1992.

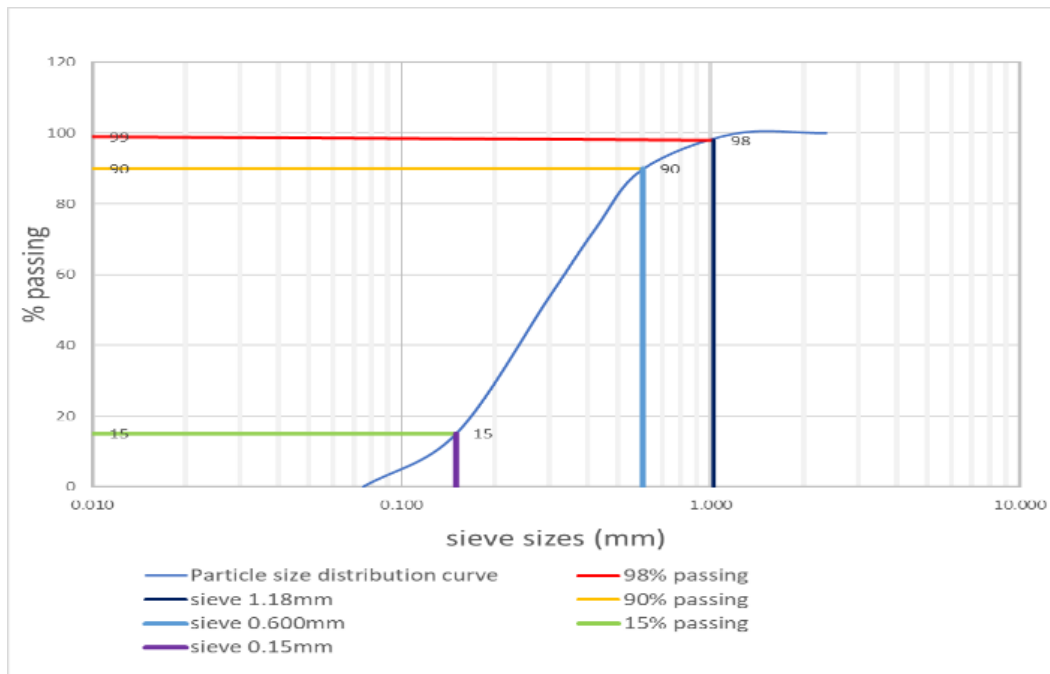
#### 4.2.2 Fresh concrete workability

All concrete mixes were measured for their workability as a slump in millimeters, to study the significance effect of replacement of cement with RGP and coarse granitic aggregate with PKS. The results of workability of concrete are shown in Fig. 17. The slump value shows that a concrete mix with only 25% PKS ( $M_{pk}$ ) partial replacement of coarse granitic aggregate was lower than that of the control mix (MC). However, with RGP partial replacement of limestone Portland cement and 25% PKS replacement of coarse aggregate in percentages of 5, 10, 15, 20 and 25 ( $M_{25,5}$ ,  $M_{25,10}$ ,  $M_{25,15}$ ,  $M_{25,20}$  and  $M_{25,25}$ ), concrete workability increased accordingly with increase in the rate of RGP replacement of cement as 60, 65, 70, 72 and 80mm respectively. This result confirms the findings of Kumar and Chaudhary [8] that the workability of concrete made utilizing waste glass as cement replacement increased with replacement level. They alluded the increment was due to the expanding substance of waste glass which is hydrophobic. Similar trend was reported by Chikhalikar and Tande [28], Gunalaan and Seri [29], and Kumarappan [30]. The increase in slump of concrete can be attributed to the fact that the RGP particles have a smoother surface that do not absorb water easily as compared to the cement which allows for better and improved workability of the concrete mixes at the same water content.





**Fig. 15. Particles size distribution of PKS**

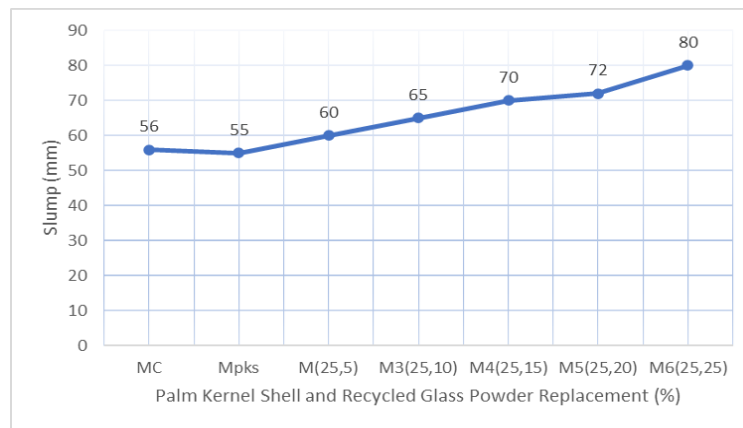


**Fig. 16. Particles size distribution of fine aggregate**

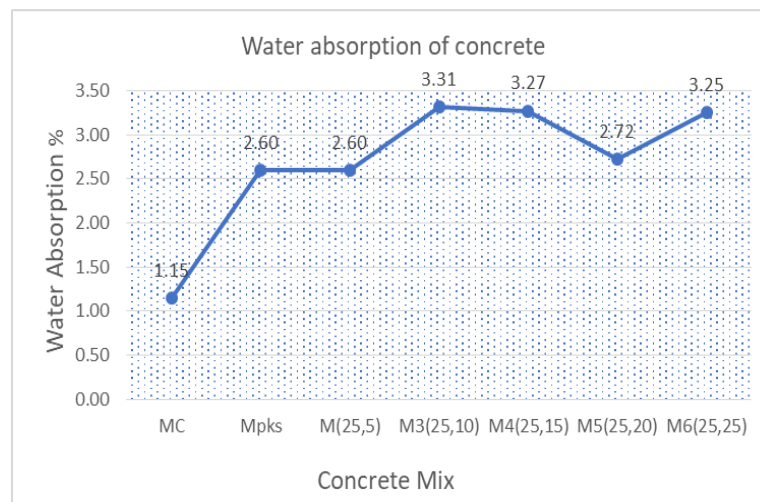
The slump of the control mix was 56mm, whereas for the mix with 25% PKS replacement of coarse granitic aggregate and 25% RGP to cement, slump increased to 80mm. The reduction in slump value from that of the control mix (MC) when 25% PKS replacement of coarse granitic aggregate ( $M_{pks}$ ) was effected may be attributed to the fact that PKS absorbs water more than the coarse granitic aggregate.

#### 4.2.3 Water absorption of hardened concrete

The durability of concrete depends on the rate at which hardened concrete absorbs water, a higher pore structure of concrete results in less durable concrete, whereas the less the pore structure of concrete the higher the durability of the concrete. The water absorption characteristics of concrete for the various mixes



**Fig. 17. Effect of Replacement of 25% PKS and RGP on workability of concrete**



**Fig. 18. Water absorption of concrete mixes**

are shown in Table 5 of the Appendices and Fig. 18 graphically presents the results.

From Fig. 18, the water absorption of concrete mixes shows that the control mix (MC) has the lowest water absorption rate of 1.15% as compared to the mix comprising of PKS as partial replacement of coarse aggregate only ( $M_{pkS}$ ). The result also shows that the rate of water absorption of  $M_{pkS}$  increases above the control mix (MC) of 1.15% to 2.6%. At the introduction of 5% RGP content to the mix of concrete consisting of 25% PKS the water absorption rate of the concrete remains the same, but further increase in RGP content to 10% led to an increase in the water absorption of the concrete to 3.31%. Subsequent increase in percentage of RGP to 15% saw a minor decrease in water absorption of the concrete to 3.27%. At 20% replacement of cement with RGP the rate of water absorption further reduced to

2.72% and upon further replacement of cement at 25% RGP the absorption increased to 3.25%. Similar kind of decrease and increase in trend of water absorption of concrete due to the replacement of RGP in percentages to cement was reported in previous investigations by Nwaubani and Poutos [31] and Lalitha et al. [11]. This trend of water absorption of the concrete consisting of 25% PKS replacement to coarse aggregate and varying percentage replacement of cement with RGP can be attributed to the combination of both PKS and RGP in the concrete while the PKS have a high water absorption rate and a low bulk density compared to that of the coarse aggregate, the RGP with a low specific gravity of 2.58 compared to that of cement of 3.15 [16]. Also considering the pozzolanic response among the active silica and the calcium hydroxide, this response produces further gel which fills the pores between particles, as well as segments the nonstop capillary

spaces in the concrete, that reduces the permeability of the concrete and declines the water absorption rate of the concrete. The increase of water absorption of concrete with the increase in RGP content in concrete consisting of 25% PKS replacement to coarse aggregate may be due to existence of free silica in the microstructure of concrete which causes feebleness in the bond among various mechanisms of concrete.

#### 4.2.4 Density of concrete

The concrete density, based on the 7 and 28 days of casting 150mmx150mmx150 mm cubes at the time of testing, was determined and measurements of concrete density are given in Table 6 of the Appendices and presented graphically in Fig. 19. The figure shows that the density of concrete made up of 25% PKS as a partial replacement for coarse aggregate was lower relative to the control mix (MC). With the addition of RGP as a partial replacement to limestone Portland cement in various percentages, the concrete densities further decreased up to 10% RGP replacement but increased at 15% replacement, remained constant to 20% replacement and a slight increase at 25% replacement of cement with RGP for age 7 days. The change in density followed same trend for age 28, except that slight decrease occurred at 25% replacement of cement with RGP to match with the same value for age 7 days. Similar kind of decrease in trend of density of concrete due to the replacement of

RGP to cement was reported in previous studies by Vasudeva et al. [32] and Mašek et al. [33] who concluded that decrease in densities compared to the control mix(MC) as a result of replacement of cement with RGP in percentages could be attributed to the decrease in weight of concrete due to the percentage rise in glass powder and also specific gravity of the RGP i.e., 2.85 is less than that of cement i.e., 3.15 (Portland Cement Association [34]). Nevertheless, the low specific gravity of PKS could also be matter of concern.

#### 4.2.5 Compressive strength of concrete

The compressive strength of the various concrete mixes was estimated at age 7 days and 28 days to study the effect of partial replacement of coarse granitic aggregate and cement with 25% PKS and various percentages of RGP. The results are given in Table 7 of the Appendices.

The compressive strengths of concrete with 25% PKS replacement to coarse aggregate at various RGP replacements of cement for 7 and 28 days are shown in Figs. 20 and 21. From Fig. 21 the effects of replacement of RGP and palm 25% kernel shell on compressive strengths of concrete show that the compressive strength of concrete decreases from 25N/mm<sup>2</sup> for normal mix concrete (MC) to 15.85N/mm<sup>2</sup> for concrete containing 25% PKS as a replacement to coarse aggregate (M<sub>pks</sub>) without cement replacement with RGP indicating lower strength of the PKS. However, with 5% RGP replacement of cement in M<sub>pks</sub>, the compressive strength remains

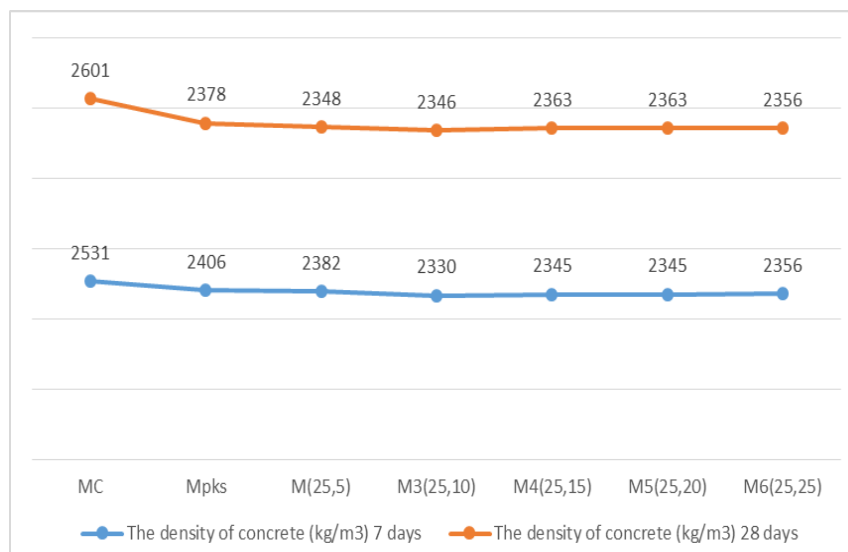
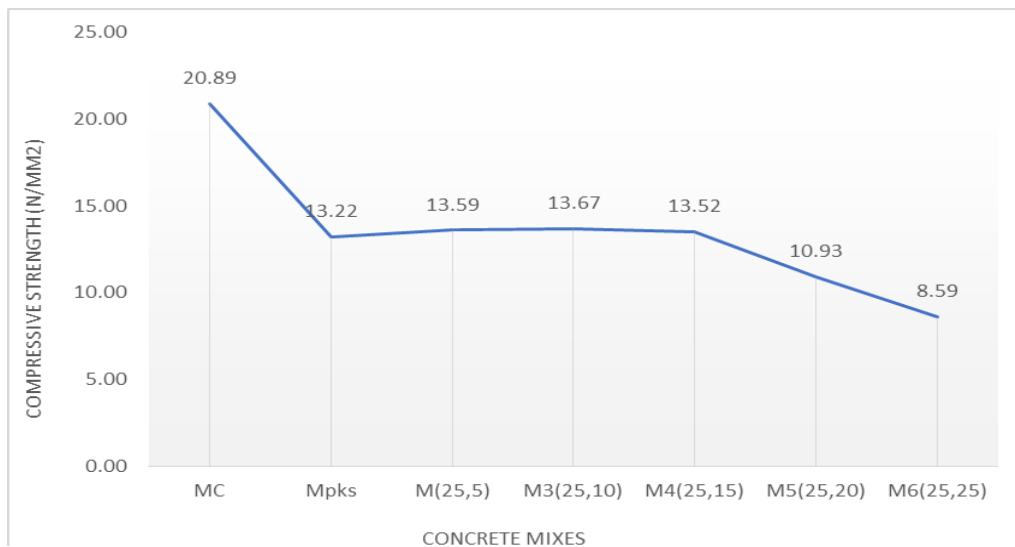
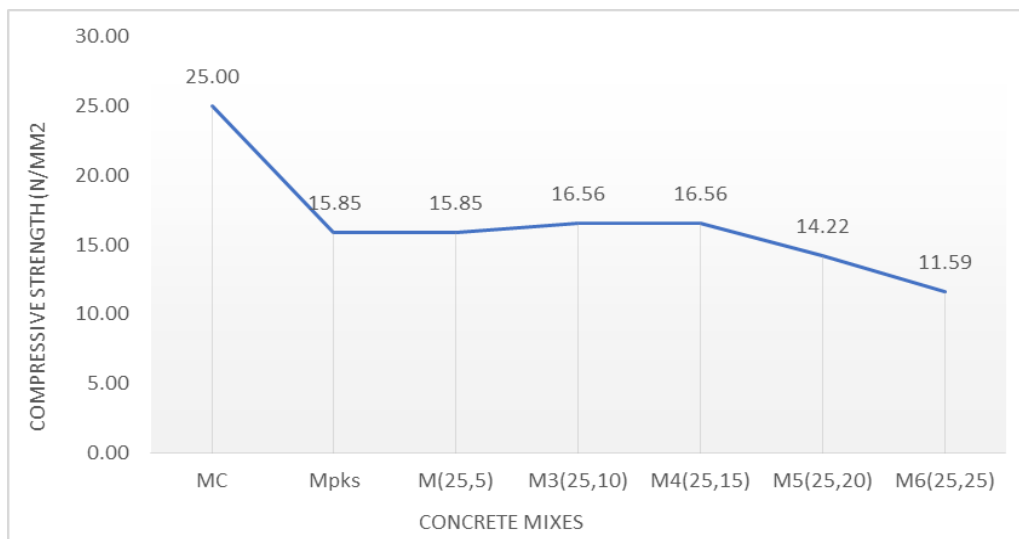


Fig. 19. Density of 7 and 28 days of concrete mixes



**Fig. 20. 7th day compressive concrete strength of various RGP with 25% PKS replacement to granitic coarse aggregate**



**Fig. 21. 28<sup>th</sup> day compressive concrete strength of various RGP with 25% PKS replacement to granitic coarse aggregate**

15.85N/mm<sup>2</sup> while 10% to 15% replacement of cement with RGP resulted in a rise in compressive strength of concrete (from 15.85 to 16.56N/mm<sup>2</sup>). Further increases in RGP replacement of (20% to 25%) of cement rather led to a significant decrease in the compressive strength of concrete to 11.59N/mm<sup>2</sup> at 20% RGP replacement after 28 days. On the other hand, 7<sup>th</sup> day compressive strength test result shows a decrease in strength for the concrete mix with 25% PKS replacement for coarse aggregate (M<sub>pkₛ</sub>) relative to the control mix (MC). However, with the introduction of 5% RGP replacement of cement in M<sub>pkₛ</sub>, concrete strength increases from

13.22 to 13.59N/mm<sup>2</sup>. An additional increase (10%) in RGP replacement of cement saw a further rise in compressive strength to 13.67N/mm<sup>2</sup> but gradually decreased to 13.52 at 15% RGP replacement (which is not the case for 28 day); and sharply dropped to 8.59 at 25% RGP replacement. These trends were reported in previous researches by Kumar and Chaudhary [8] and Khatib et al. [35]. In general, the decrease in compressive strength of concrete containing 25% PKS (M<sub>pkₛ</sub>) compared to the control mix (MC), can be attributed to a low bulk density and a low specific gravity of PKS compared to that of the coarse aggregate. At the



replacement of 10% to 15% RGP content in the concrete containing 25% PKS, compressive strength increases to  $16.56\text{N/mm}^2$ . The surge in compressive strength of the concrete was as result of the pozzolanic action of the finely ground RGP since the RGP acts as a pozzolanic material in the concrete. A further increase in RGP to 20% and 25% saw a reduction in the compressive strength of the concrete to  $11.59\text{N/mm}^2$ . The reduction in compressive strength of the concrete with the increase in the RGP content may possibly be due to short-term result since in such short term the pozzolanic properties would not become evident. Nassar and Soroushian [9], Neville [10] and Lalitha, et al. [11] reveal that the decrease in compressive strength can be attributed to the slow pozzolanic response that happens between the reactive silica in the RGP and the calcium hydroxide produced from the cement hydration. This response produces extra gel that raises the strength at later ages. However, in absence of the assumption, in order to use RGP as pozzolana in concrete with 25% PKS as a partial replacement for coarse aggregate, at most 15% RGP replacement to cement is recommended.

## 5. CONCLUSION

These experimental examinations were conducted to review the suitability of RGP as a partial replacement of cement in concrete with 25% PKS as partial replacement of coarse granitic aggregate. Particle size distribution of RGP and PKS, optimum percentages of RGP as pozzolana, Workability, Density, Water absorption and compressive strength of concrete were tested by replacing cement with RGP at varying percentages in concrete with 25% PKS as partial replacement of coarse granitic aggregate. The particle size distribution of the various aggregates used was duly measured through sieve analysis conducted and they satisfied the appropriate codes. The observation made at the top of the analysis shows that:

1. Varied optimum percentages of RGP as pozzolana was obtained at 15% replacement of cement for compressive strength and 20% for good workability, 15% for density and 5% for water absorption of the concrete.
2. The workability of the concrete with 25% PKS increases with increase in RGP content replacement for cement. The optimum workability of concrete was 80mm at 25% replacement of RGP to cement.

3. The density of the concrete decreases with increase in RGP replacement of cement, nevertheless all concrete densities were within the bounds of normal weight concrete as specified in standard requirements.
4. The water absorption of the concrete increased with a rise in the RGP content.
5. The rise of RGP to 15% as a replacement to cement gave rise in compressive strength of concrete to  $16.56\text{N/mm}^2$  at 28 days age, while further increase in RGP resulted in a decrease in the compressive strength of the concrete for all ages.
6. Hence, to use RGP as pozzolana in concrete with 25% PKS as a partial replacement for coarse aggregate, at most 15% RGP replacement to cement is recommended.

## CONSENT AND ETHICAL APPROVAL

It is not applicable.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Madlool NA, Saidur R, Hossain MS, Rahim NA. A critical review on energy use and savings in the cement industries. *Renewable and Sustainable Energy Reviews*. 2011;15(4):2042–2060.
2. Kankam CK. Potential for using palm kernel shell as aggregates in Portland cement concrete. In *Proc. 25<sup>th</sup> Silver Anniversary of Int. Conference on Our World of Concrete Structures*, Singapore; 2001.
3. Acheampong A, Kankam CK, Ayarkwa J. Shear behavior of palm kernel shell reinforced concrete beams without shear reinforcement. Influence of beam depth and tension steel. *Journal of Civil Engineering and Construction Technology*. 2016;7(2):8-19.
4. Khankhaje E, Salim MR, Mirza J, Hussin MW, Rafieizonooz M. Properties of sustainable lightweight pervious concrete containing oil palm kernel shell as coarse aggregate. *Construction and Building Materials*. 2016;126:1054–1065.
5. Mannan MA, Ganapathy C. Engineering properties of concrete with oil palm shell as

- coarse aggregate. *Journal of Construction, Building and Materials*. 2002;16:29-34.
6. Ikumapa OM, Akinlab ET. Composition, Characteristics and Socioeconomic Benefits of Palm Kernel Shell Exploitation- An Overview. *Journal of Environmental Science and Technology*. 2018;11(5):220–232.
  7. Falade F. The use of palm kernel shell as course aggregate in concrete. *Journal of Housing Science*. 1992;16(3):213-219. *International Journal of Agriculture, Environment and Bioresearch*. 2017;2(02). ISSN: 2456-8643 Available:www.ijaeb.orgPage 239
  8. Kumar S, Chaudhary M. Utilization of waste glass as cement replacement in PPC concrete. *International Journal of Trend in Scientific Research and Development*. 2018b;2(3):295–300.
  9. Nassar RUD, Soroushian P. Use of milled waste glass in recycled aggregate concrete. *Proceedings of the Institution of Civil Engineers - Construction Materials*. 2013;166(5):304–315.
  10. Neville AM. *Properties of Concrete*. 4th ed. Pearson Education Ltd. Harlow Pearson Education; 2005.
  11. Lalitha S, Alaguraj M, Divyapriya AMP. Experimental study on use of waste glass powder as partial replacement to cement in concrete. *Global Journal of Engineering Science and Researches*. 2016;2348–8034.
  12. Nassar RUD, Soroushian P. Field investigation of concrete incorporating milled waste glass. *The Journal of Solid Waste Technology and Management*. 2011;37(4):307–319.
  13. British Standards Institution. BS 1881-122:2011. Testing concrete. Part 122: Method for determination of water absorption. BSI London; 2011.
  14. British Standards Institution. BS EN 12350-2:2000 testing fresh concrete. Slump test. BSI London; 2000.
  15. American Concrete Institute ACI 211.1-91. Standard Practice for selecting proportions for normal, heavyweight and mass concrete. Detroit; 1991.
  16. Dzivenu CK. The potential use of recycled glass as a pozzolana in portland cement concrete with palm kernel shell as partially replaced aggregate. MSc Thesis, Department of Civil Engineering, KNUST, Kumasi, Ghana; 2020.
  17. Shi C, Wu Y, Riefler C, Wang H. Characteristics and pozzolanic reactivity of glass powders. *Cement and Concrete Research*. 2005;35(5):987-993.
  18. British Standards Institution. BS EN 197-1 : 2011. Cement composition, specifications and conformity criteria for common cements. BSI London; 2011.
  19. British Standards Institution. BS EN 12620:2013 Aggregates for concrete. BSI London; 2013.
  20. Portland Cement Association (PCA Sh Kosmatka and Wc Panarese). Design and control of concrete mixtures; 1988.
  21. Khatib J, Negim E, Sohl H, Chileshe N. Glass powder utilisation in concrete production. *European Journal of Applied Sciences*. 2012;4(4).
  22. British Standards Institution. BS EN 933-1:1997 Tests for geometrical properties of aggregates. Part 1, Determination of particle size distribution -- sieving method. BSI London; 1997.
  23. British Standards Institution. BS EN 12390-2. Making and curing specimens from fresh concrete for strength. BSI London; 2011.
  24. British Standards Institution. BS 812-2:1995 Testing aggregates: part 2: methods of determination of density. London: British Standards Institution; 1995.
  25. British Standards Institution. BS 8680:2020 Water quality, water safety, plans. Code of practice. London: British Standards Institution. London; 2020.
  26. Olusola KO, Babafemi AJ. Effect of coarse aggregate sizes and replacement levels on the strength of palm kernel shell (PKS) Concrete. *Civil Engineering Dimension*. 2013;15(1).
  27. BS EN 1097: Part 3: 1998. Part 3: Determination of loose bulk density and voids. London: British Standards Institution. London
  28. British Standards Institution. BS EN 12390-7:2000 Testing hardened concrete. Part 7, Density of hardened concrete. BSI London; 2000.
  29. British Standards Institution. BS EN 12390-3: 2002 Testing hardened concrete. Part 3. Part 3, Compressive strength of test specimens. BSI London; 2002.
  30. Chikhalikar SM, Tande SN. An experimental investigation on characteristic properties of fibre reinforced concrete containing waste glass powder as

- pozzolana. Proceedings of 37<sup>th</sup> Conference on Our World in Concrete & Structures Singapore. 2012;2- 11.
31. Gunalaan V, Seri GK. Performance of using waste glass powder in concrete as replacement of cement. American Journal of Engineering Research (AJER). 2013;2:1-7.
  32. Kumarappan N. Partial replacement cement in concrete using waste glass. International Journal of Engineering Research & Technology (IJERT). 2013;2(10). ISSN: 2278-0181.
  33. Nwaubani SO, Poutos KI. International Journal of Application or Innovation in Engineering & Management (IJAEM); 2013.
  34. Vasudevan G, Ganis S, Pillay K. Performance of using waste glass powder in concrete as replacement of cement. American Journal of Engineering Research (AJER). 2013;02(12):175–181.
  35. Małek M, Łasica W, Jackowski M, Kadela M. Effect of waste glass addition as a replacement for fine aggregate on properties of mortar. Materials. 2020; 13(14):3189.

## APPENDICES

Table 5. Water absorption of various concrete mixes

Specimen ID	% palm kernel shell	% glass powder	Water absorption				
			Wet weight (grams)	Dry weight (grams)	Water absorbed (grams)	% water absorbed	% increase
MC			8.8	8.7	0.1	1.15	0
M <sub>pks</sub>	25		7.9	7.7	0.2	2.60	1.45
M <sub>(25,5)</sub>	25	5	7.9	7.7	0.2	2.60	1.45
M <sub>3(25,10)</sub>	25	10	7.8	7.55	0.25	3.31	2.16
M <sub>4(25,15)</sub>	25	15	7.9	7.65	0.25	3.27	2.12
M <sub>5(25,20)</sub>	25	20	7.55	7.35	0.2	2.72	1.57
M <sub>6(25,25)</sub>	25	25	7.95	7.7	0.25	3.25	2.10

Table 6. Density of 7 and 28 days of concrete mixes

Specimen ID	The density of concrete (kg/m <sup>3</sup> )	
	7 days	28 days
MC	2531	2601
M <sub>pks</sub>	2406	2378
M <sub>(25,5)</sub>	2382	2348
M <sub>3(25,10)</sub>	2330	2346
M <sub>4(25,15)</sub>	2345	2363
M <sub>5(25,20)</sub>	2345	2363
M <sub>6(25,25)</sub>	2356	2356

Table 7. Compressive strength of concrete mixes

Specimen ID	7 <sup>th</sup> and 28 <sup>th</sup> compressive strength N/mm <sup>2</sup>			
	7 Days		28 Days	
	Crushing load (kN)	Compressive strength (N/mm <sup>2</sup> )	Crushing load (kN)	Compressive strength (N/mm <sup>2</sup> )
M <sub>C</sub>	470	20.89	562.5	25
M <sub>pks</sub>	297.5	13.22	356.67	15.85
M <sub>(25,5)</sub>	305.67	13.59	356.67	15.85
M <sub>3(25,10)</sub>	307.5	13.67	372.5	16.56
M <sub>4(25,15)</sub>	304.17	13.52	372.5	16.56
M <sub>5(25,20)</sub>	245.83	10.93	320	14.22
M <sub>6(25,25)</sub>	193.33	8.59	260.83	11.59

© 2022 Dzivenu et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:

<https://www.sdiarticle5.com/review-history/92254>