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

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 kennel 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 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, and 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 (Madlool et al., 2011). 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 (Kankam, 2001; Acheampong et al., 2016; Khankhaje et al., 2016; Mannan and Ganapathy, 2002; Ikumapa and Akinlab, 2018). Falade (1992) 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 (2018) 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 (2013), Neville (2005) and Lalitha, et al. (2016) 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 (Nassar and Soroushian, 2011), 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. 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 (Shi et al.,2005)

Compound	Waste-Glass (Nassar & Soroushian 2012)	Cement (Ryou et al., 2006)
SiO_2	68	20.3
Al_2O_3	7	4.7
Fe_2O_3	< 1	3

CaO	11	61.8
MgO	< 1	3.3
K_2O	< 1	0.6
Na_2O	12	0.2
SO_3	-	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 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 (2013) 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 (Khankhaje et al., 2016); (Olusola and Babafemi, 2013) and clean safe drinking water from Ghana water company that complied with requirements of BS 8680 (2020)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).


Fig. 1: Preparation of RGP

2.1.1.1 Physical properties of RGP

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

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

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.

Fig. 2: Specific gravity of RGP

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 (figures 3a, b).

(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

2.1.2 Fine aggregate

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

2.1.2.1 Sieve analysis of the fine aggregate

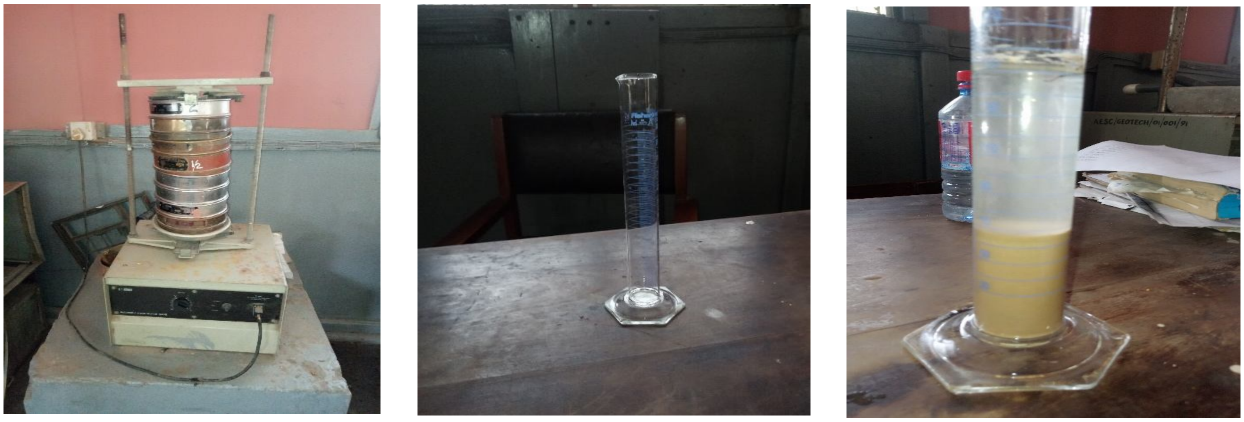
The fine aggregate was first dried and weighed. The weighed sand was washed to remove all impurities and oven-dried for 24 hours. The oven-dried sand was weighed again and the value noted. Sieves of various sizes and pan were cleaned and arranged according to sizes in descending order from top with the pan at the bottom. The oven-dried sand was placed on to 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

Silt content (%) = $\frac{t \ X \ 100}{T}$……………………………………………………...Eq. 2

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



(a) Fine aggregate and sieves mounted on mechanical shaker

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

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 (as shown in figure 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.

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 (fig. 6a, b, c). It was then oven dried at 105℃ for 24hours and weighed after air cooling at room temperature (M4). Relative density and water absorption were computed as follows:

Relative density on an oven-dried basis = $\frac{M4}{M1-(M2-M3)}$ …………………………… Eq. 3

Relative density on a saturated surface dry basis = $\frac{M1}{M1-(M2-M3)}$ ……………………… Eq. 4

Apparent relative density = $\frac{M4}{M4-(M2-M3)}$ ……………………………………...……. Eq. 5

Water absorption (% of dry mass) = $\frac{100(M1-M4)}{M4}$………………………….……………….. Eq. 6

Where: M1 is the mass of saturated surface dry coarse aggregate in the air in grams

M2 is the mass of pyknometer + water + coarse aggregate in grams

M3 is the mass of pyknometer + water in grams

M4 is the mass of oven-dried coarse aggregate in grams

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

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 (Figure 7). The loose bulk and compacted bulk densities were computed as follows:

$\rho = \frac{M}{V}$ …………………………………………………………………………… Eq. 7

where: ρ = Bulk density of loose or compacted coarse aggregate in kg/m^3; M= Mass in kg; V = volume in m^3.

Fig. 7: Bulk density of coarse aggregate

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 figure 8.

Fig. 8: Sample of PKS.

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.

Mix proportion (ratio)					
Specimen ID	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

% replacement of cement and coarse aggregate					
Specimen ID	Cement (%)	RGP (%)	Fine aggregate (%)	Coarse aggregate (%)	PKS (%)
MC	100	0	100	100	0
M_{pks}	100	0	100	75	25
$M_{(25,5)}$	95	5	100	75	25
$M_{(25,10)}$	90	10	100	75	25
$M_{(25,15)}$	85	15	100	75	25
$M_{(25,20)}$	80	20	100	75	25
$M_{(25,25)}$	75	25	100	75	25

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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.

Fig. 9: Mixing of concrete.

All the stages involved in the mixing of the various concrete materials into the final concrete test specimens are illustrated in Figure 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 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 figure 10.

Fig. 10: Slump test

2.2.2Casting 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(2000) 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).

Fig. 11: Casting and curing of concrete specimens

3. TESTING OF SPECIMENS

3.1 Compressive strength of cubes

Compressive strength test was carried out in accordance with BS EN 12390-3:2002. 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.

Fig. 12: Testing of cubes.

The compressive strength was calculated as:

$$\sigma = \frac{P}{A} \quad \text{.......... Eq. 8}$$

Where, σ = Compressive strength (N/mm^2); P = Maximum load a cube sustained (N); A = cross-sectional Ares of a cube (mm^2)

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

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 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. 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:

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

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.

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^3)	1408.76	558.87	-	-
Bulk density (Compacted) (kg/m^3)	1635.86	664.69	-	-
Silt test (%)	-	-	-	6.06

4.2.1 Grading of materials

4.2.1.1 RGP (Fineness)

The sieve analysis displayed in figure 13 shows that 98.7% of the **RGP** passed through sieve size of 300µm, while 73.6% passed through sieve 150µm and 29% through sieve 75µm. The result proves that the RGP used for this study met the pozzolanic physical property in line with the finding of Shi et al. (2005) that the pozzolanic properties of glass are first notable at particle sizes below approximately 300µm; and, that below 100µm, 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.

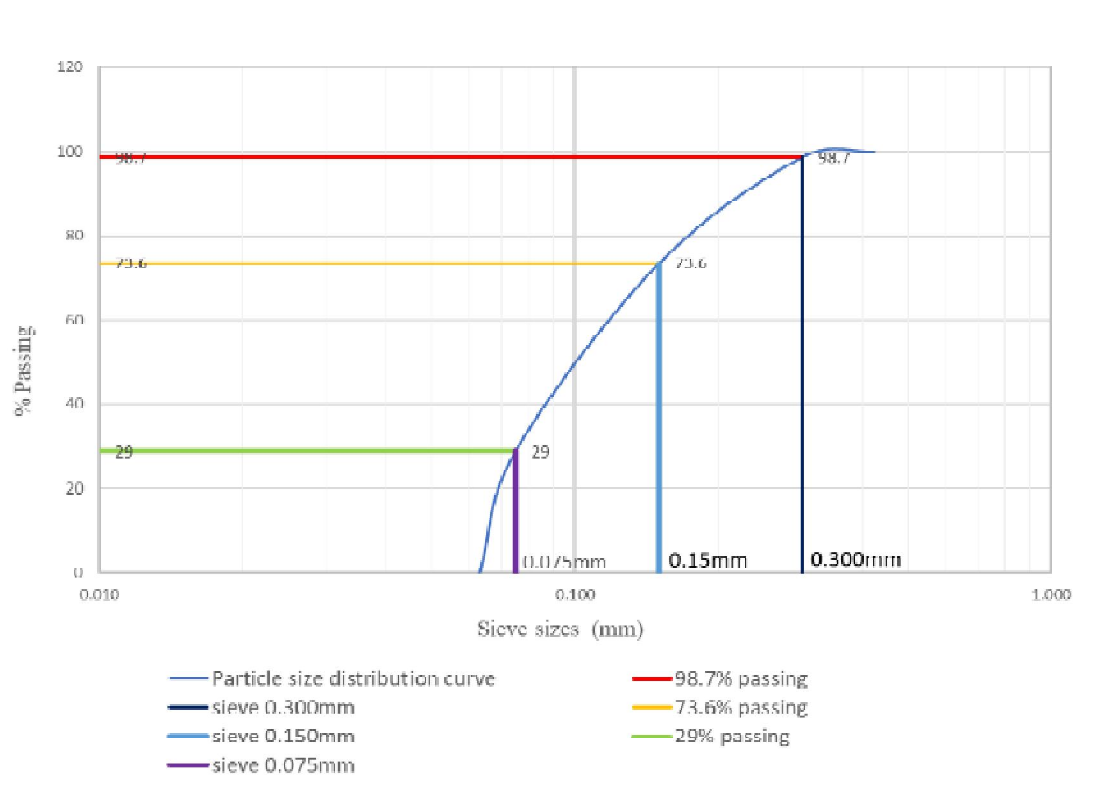

Fig. 13: Particle size distribution of RGP

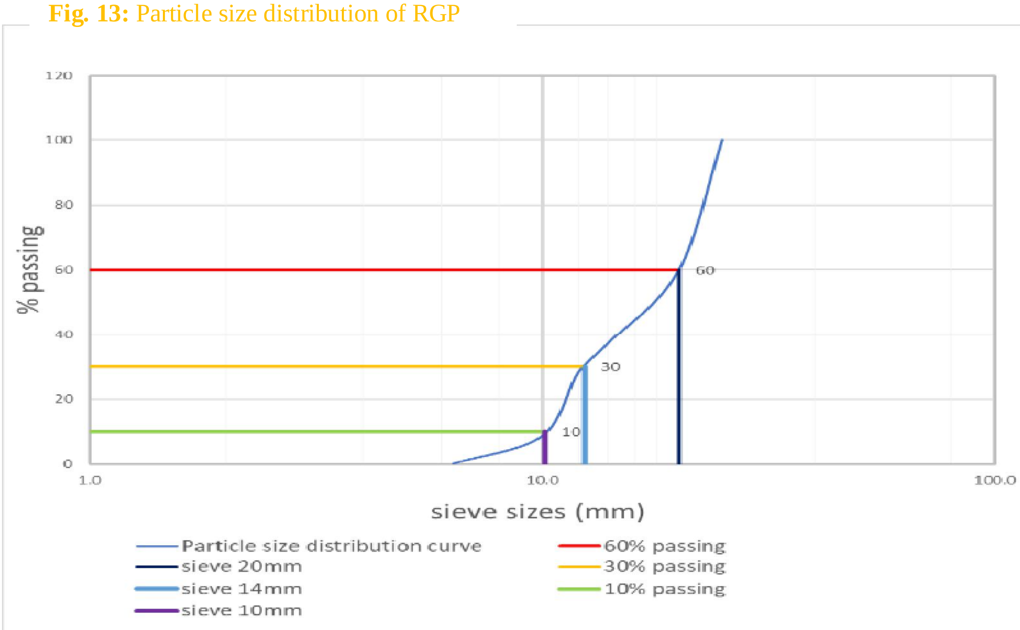

Fig. 14: Particle size distribution of coarse aggregate.

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 figure 14. Also, the particle size distribution of PKS in figure 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 figure 16 shows the grading falls within the appropriate limits of the requirement of the BS 882: 1992.

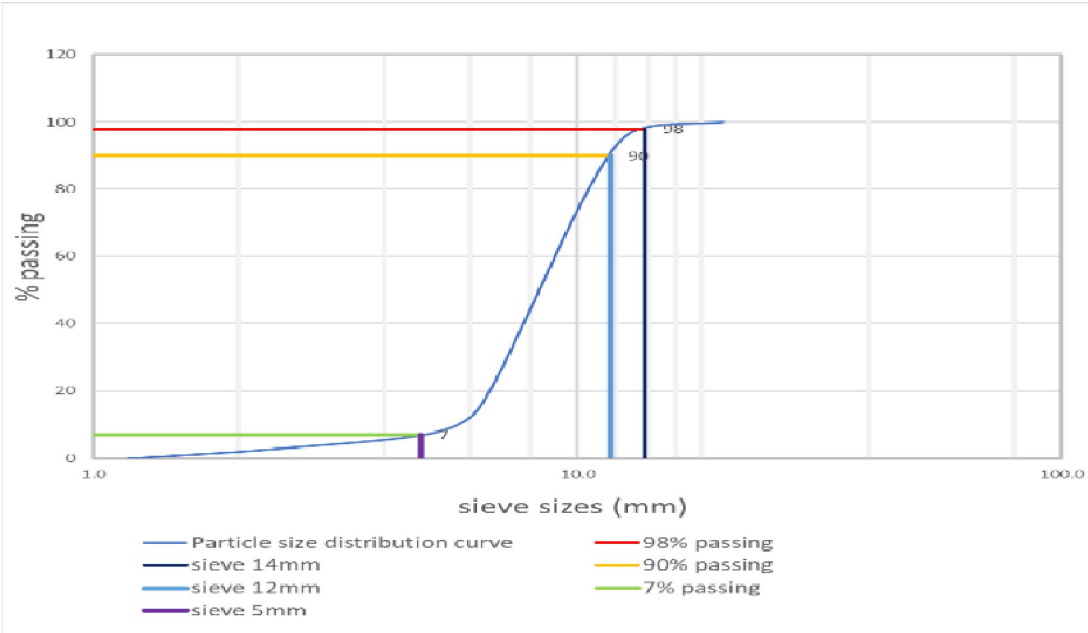

Fig. 15: Particles size distribution of PKS.

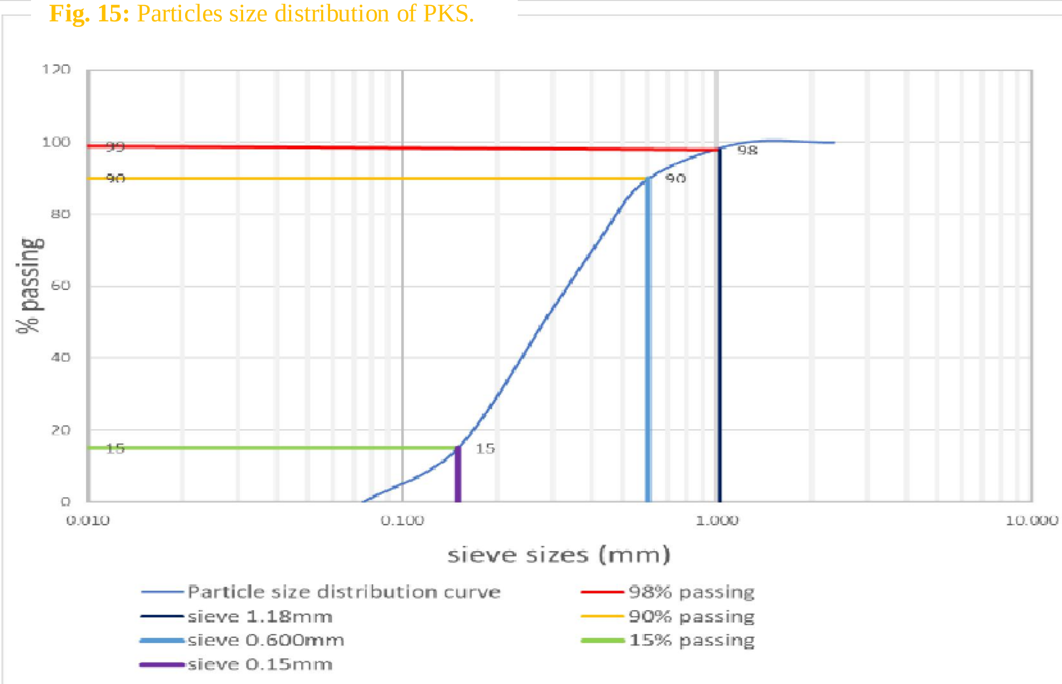

Fig. 16: Particles size distribution of fine aggregate

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 figure 17. The slump value shows that a concrete mix with only 25% PKS (M_{pks}) 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 (2018) 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 (2012), Gunalaan and Seri (2013), and Kumarappan (2013). 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.

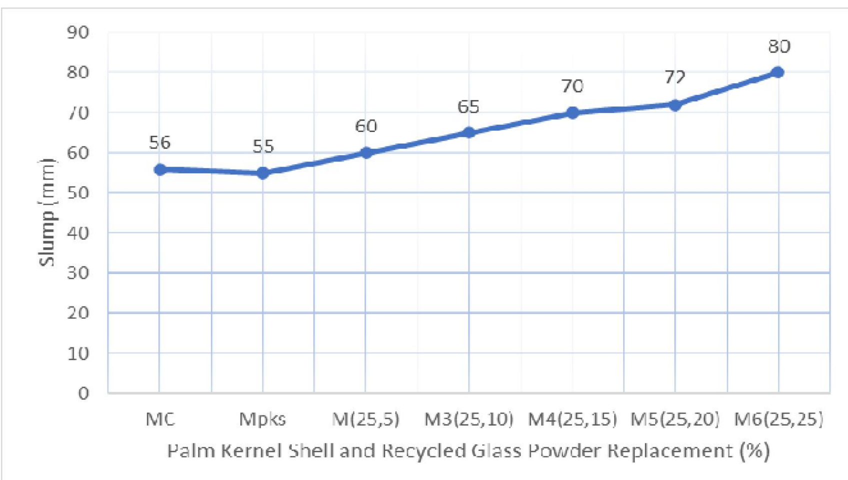

Fig. 17: Effect of Replacement of 25% PKS and RGP on Workability of Concrete.

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

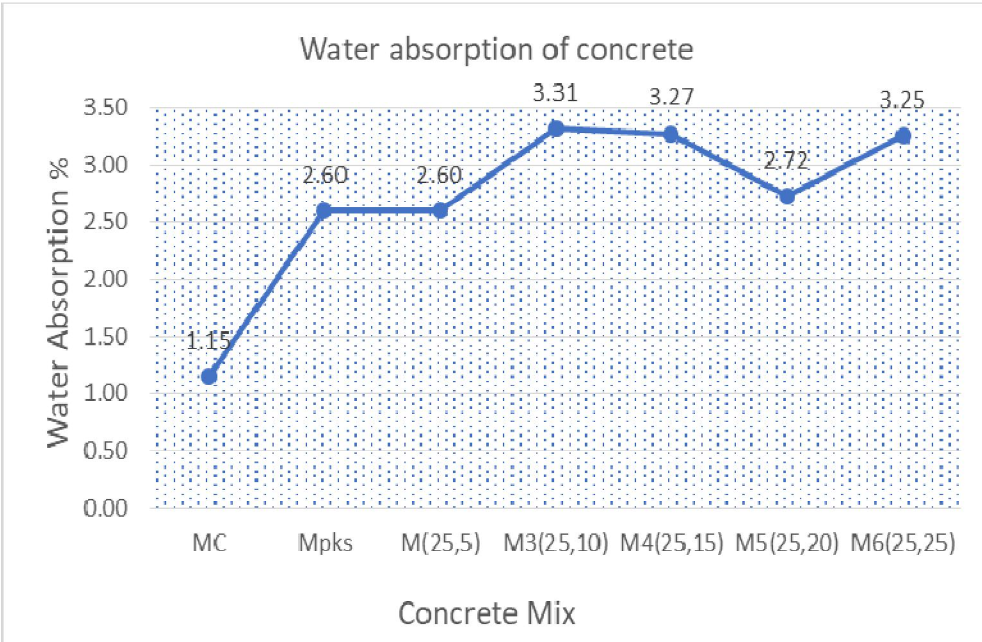

Fig. 18: Water Absorption of concrete mixes.

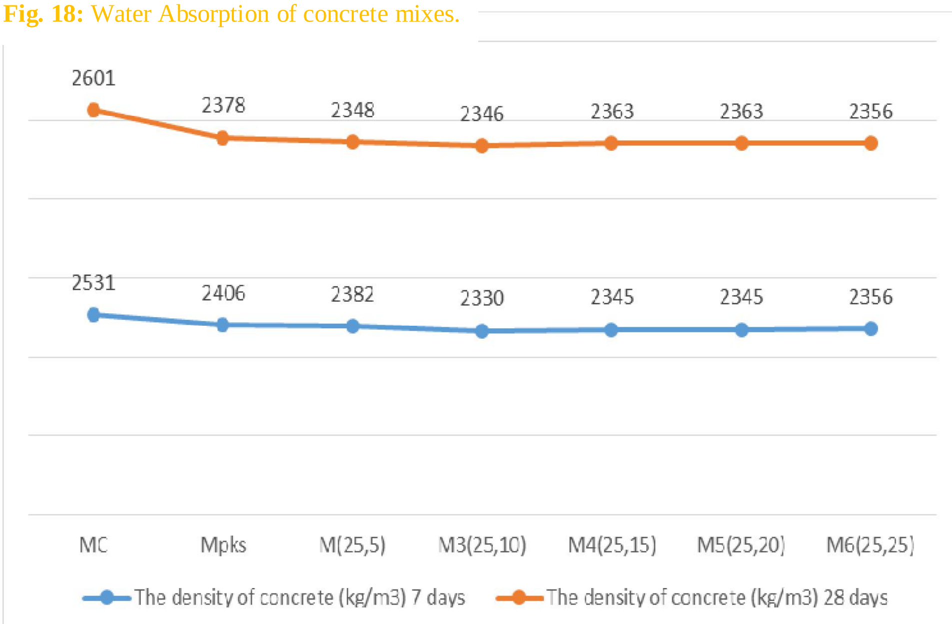

Table 19: Density of 7 and 28 days of concrete

From figure 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 (2013) and Lalitha et al. (2016) 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 (BS EN 197-1:2011) . 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 figure 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. (2013) and Małek et al. (2020) 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 (Pca, Sh Kosmatka and Wc Panarese, 1988). 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.

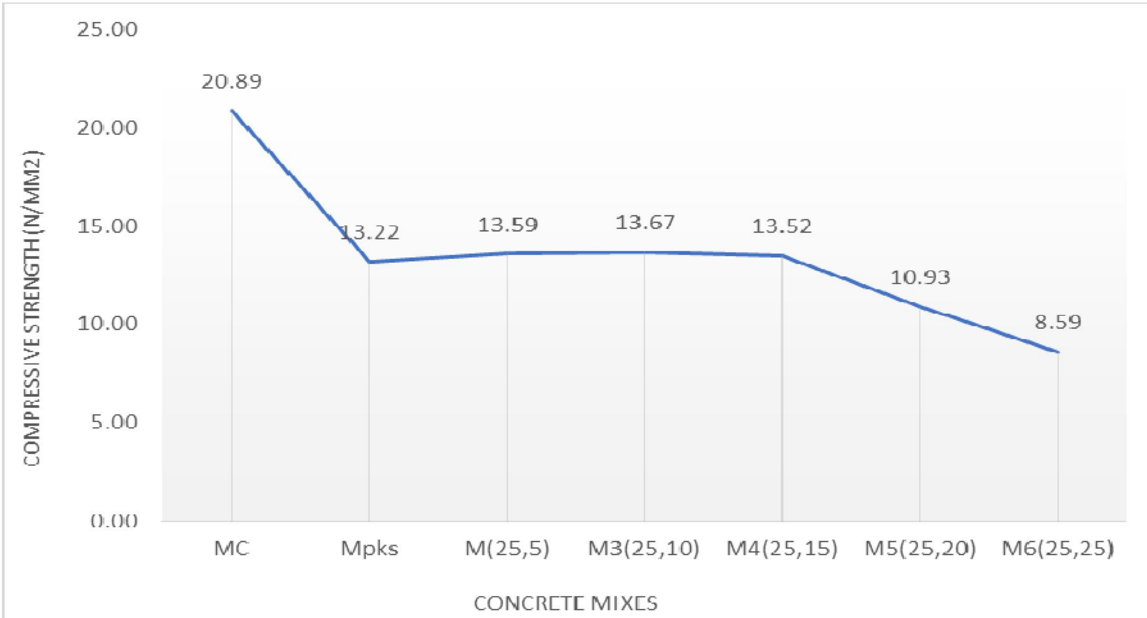

Fig. 20: 7th day compressive concrete strength of various RGP with 25% PKS replacement to granitic coarse aggregate.

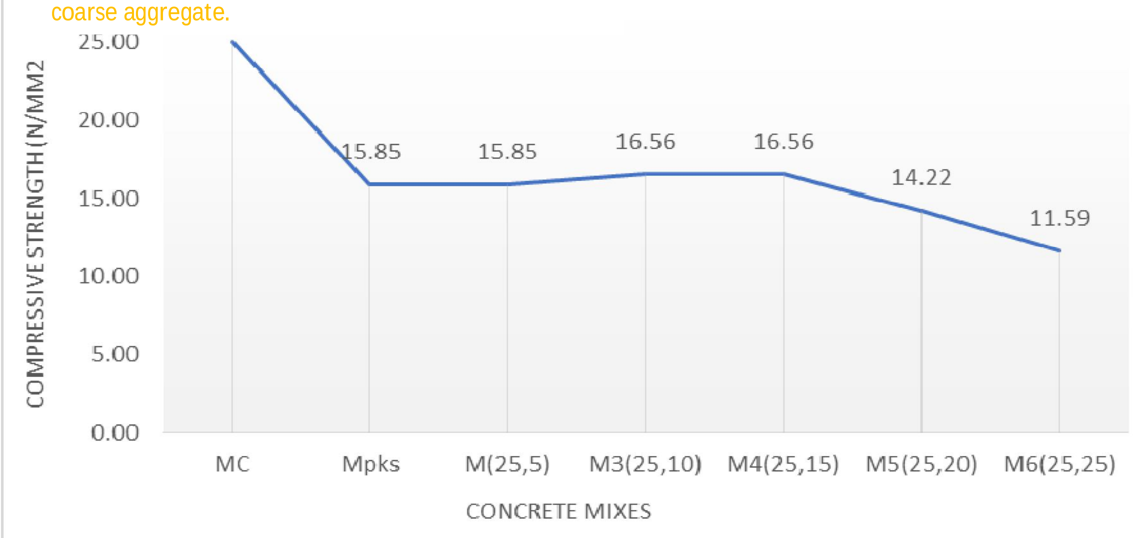

Fig. 21: 28th day compressive concrete strength of various RGP with 25% PKS replacement to granitic coarse aggregate.

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 figures 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^2 for normal mix concrete (MC) to 15.85N/mm^2

for concrete containing 25% PKS as a replacement to coarse aggregate (M_{pks}) without cement replacement with RGP indicating lower strength of the PKS. However, with 5% RGP replacement of cement in M_{pks}, the compressive strength remains 15.85N/mm^2 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^2). 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^2 at 20% RGP replacement after 28 days. On the other hand, 7th day compressive strength test result shows a decrease in strength for the concrete mix with 25% PKS replacement for coarse aggregate (M_{pks}) relative to the control mix (MC). However, with the introduction of 5% RGP replacement of cement in M_{pks}, concrete strength increases from 13.22 to 13.59N/mm^2. An additional increase (10%) in RGP replacement of cement saw a further rise in compressive strength to 13.67N/mm^2 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 (2018) and Khatib et al. (2012). In general, the decrease in compressive strength of concrete containing 25% PKS (M_{pks}) 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 16.56N/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 11.59N/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 (2013), Neville (2005) and Lalitha, ea al. (2016) 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 .56N/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.

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Appendices

Table 5: Water absorption of various concrete mixes.

WATER ABSORBTION							
Specimen ID	% palm kernel shell	% glass powder	Wet weight (grams)	Dry weight (grams)	Water absorbed (grams)	% water absorbed	% increase
MC			8.8	8.7	0.1	1.15	0
Mpks	25		7.9	7.7	0.2	2.60	1.45
$M_{(25,5)}$	25	5	7.9	7.7	0.2	2.60	1.45
$M3_{(25,10)}$	25	10	7.8	7.55	0.25	3.31	2.16
$M4_{(25,15)}$	25	15	7.9	7.65	0.25	3.27	2.12
$M5_{(25,20)}$	25	20	7.55	7.35	0.2	2.72	1.57
$M6_{(25,25)}$	25	25	7.95	7.7	0.25	3.25	2.10

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

The density of concrete (kg/m^3)

Specimen ID	7 days	28 days
MC	2531	2601
Mpks	2406	2378
$M_{(25,5)}$	2382	2348
$M3_{(25,10)}$	2330	2346
$M4_{(25,15)}$	2345	2363
$M5_{(25,20)}$	2345	2363
$M6_{(25,25)}$	2356	2356

Table 7: Compressive Strength of Concrete Mixes

7th and 28th Compressive Strength N/mm2				
	7 Days		28 Days	
Specimen ID	Crushing load (kN)	Compressive strength (N/mm^2)	Crushing load (kN)	Compressive strength (N/mm^2)
M_C	470	20.89	562.5	25
M_{pks}	297.5	13.22	356.67	15.85
$M_{(25,5)}$	305.67	13.59	356.67	15.85
$M3_{(25,10)}$	307.5	13.67	372.5	16.56
$M4_{(25,15)}$	304.17	13.52	372.5	16.56
$M5_{(25,20)}$	245.83	10.93	320	14.22
$M6_{(25,25)}$	193.33	8.59	260.83	11.59