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EFFECT OF AGGREGATE TYPE ON PROPERTIES OF PERVIOUS CONCRETE

M.A. Tijani[1*], W.O. Ajagbe[2], A.A. Ganiyu[3], O.A. Agbede[2]

[1]Department of Civil Engineering, Osun State University, Osogbo, Nigeria
[2]Department of Civil Engineering,University of Ibadan, Ibadan, Nigeria
[3]Department of Civil Engineering and Quantity Surveying, Military Technological College, Muscat, Oman

Abstract. Pervious concrete (PC) is a cheap and effective drainage system for reducing storm-water runoff in urban centers. This research aim to investigate the influence of different type of aggregate on PC properties. Three PC mixtures were prepared with different aggregate types [Granite, Gravel and Recycled Concrete Aggregate (RCA)]. Physical and strength characteristics of the aggregates were analyzed. Density, porosity, permeability as well as compressive strength of PC made with these aggregates were measured. Results showed that PC made from RCA has the highest porosity and permeability due to the porous nature of adhered mortar on RCA. However, highest density and compressive strength was obtained from granite PC followed by gravel and then RCA PC. The study concluded that aggregate type has significant influence on PC properties.

Keywords: Pervious Concrete (PC), Granite, Gravel, Recycled Concrete Aggregate (RCA), Storm water management.

Corresponding author: Murtadha Adekilekun Tijani, Osun State University, Department of Civil Engineering, Faculty of Engineering and Environmental Sciences, Osogbo, Nigeria, e-mail: *murikilekun@gmail.com*

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1 Introduction

PC is an eco-friendly concrete endorsed by United States government as a suitable measure to moderate the effect of urbanization on the surroundings. PC pavement systems allow for the infiltration of collected storm water into the ground in order to avoid flooding and recharge groundwater (Ajagbe et al., 2018). According to ACI522R (2010) PC pavement is defined as a concrete mixture that contains cement, uniformly graded coarse aggregate and water.The permeability of PC ranges from 1.4 to 12.2 mm/s, its porosity ranges from 15 to 30% while its strength ranges from 2 to 28 MPa. PC can only be used in low traffic flow areas such as footpaths, drainage pavement, parking lots and other low volume roads (Osic et al., 2015; Yap et al., 2018).

According to Jain and Chouhan (2011) the physical properties of aggregate such as size, shape and distribution influence the mechanical and hydraulic properties of PC pavements. However, aggregate type also affect the properties of PC performance. Previous studies have reported the effect of aggregates on properties of PC mixtures (Meininger, 1988; Yang & Jing, 2003; Tennis et al., 2004; Crouch et al., 2006; Kevern, 2008; Kevern et al., 2010; Lain & Zhuge, 2010; Osic et al., 2015).

The influence of different type of aggregate was studied on the freeze-thaw durability of PC by Kevern et al. (2010). Seventeen samples of coarse aggregate were collected from different areas of USA and analyzed. Correlations among the aggregate and the PC properties showed that absorption of aggregate has the maximum consequence on the freeze-thaw stability of PC.

It was concluded that aggregate need to have not less 2.5 specific gravity, absorption of not greater 2.5%, abrasion capacity of not greater 15%, and have a combined gradation near the lower gradation boundary for high durability mixtures.

The influence of aggregate characteristics and compaction drive on strength of PC was carried out by Crouch et al (2006). Crushed aggregate of different size distributions were compacted at different levels. Smooth aggregate materials were found to have high PC density at the same compaction drive. Increase in aggregate coarseness and porosity lead to decrease in PC compressive strength. Similar research by Tennis et al.(2004) on hydrologic relations of PC produce from two different rocks obtained from unlike sources showed linear relationship among density, porosity and permeability. Hydrologic properties were not considerably affected by the rock type.

Meininger (1988) employed varied aggregate sizes in PC production. Lesser PC strengths were obtained from bigger sized aggregate. Similar research conducted by Yang and Jing (2003) showed a rise in PC strength as the size of aggregate reduced. The increase in PC strength was attributed to intensification of the interface strength amid the paste and aggregate.Crouch et al. (2007) investigated the influence of aggregate on static modulus of elasticity of PC. The result indicated that the permeability, porosity and compressive strength are essentially dependent upon aggregate. It was concluded that aggregate amount, particle size distribution as well as the size of aggregate significantly affect PC properties.

Lain and Zhuge (2010) determined the influence of different type of aggregate (quartzite, dolomite, limestone) on PC performance.Dolomite was found to be aggregate with optimum performance on PC production. It was concluded that for optimum PC strength, gradation of aggregate should be monitored. Similarly, the influence of dolomite and steel slag was studied by Osic et al. (2015) on PC performance. PC made of dolomite aggregate showed greater porosity as compared to steel slag aggregate. The research concluded that the type of aggregate affect density, porosity and strength more than aggregate size.

However, the authors have found no published research data on investigating the effect of aggregate type using crushed granite, natural gravel and RCA on properties of PC. Hence, the need for this study.

2 Materials and Methods

2.1 Materials

Cement

Ordinary Portland cement of 42.5-grade was used in this study. The cement chemical properties is presented in Table 1. No admixture was used in this study.

Aggregates

Three different types of coarse aggregate were adopted for PC production as shown in Fig. 1. Mechanically crushed rough and angular granite (Fig. 1a) and smooth rounded gravel (Fig. 1b) of nominal size 10mm were obtained from local quarries situated in Ede, Nigeria. RCA adopted was acquired from a destroyed building in Lagos, Nigeria. Large sized RCA was broken into lesser size and sieved to acquire 10mm nominal size aggregate for PC production (Fig. 1c). The selected aggregate size was used because it was stated that a fairly small amount of cement is enough to coat the aggregate of 4.75 – 9.50 mm (Chandrappa & Biligiri, 2016).

Fig. 2 presented the particle size distribution for nominal size (10mm) aggregates used in this study and compare them with the upper and lower limits stipulated by BS882 (1992). The three aggregate types used were found to be within the standard range for single-sized aggregate. The physical and mechanical characteristics of aggregates utilized are presented in Table 2. The highest bulk density value was obtained from granite (1559 kg/m^3) followed by gravel (1467 kg/m^3) while the least value was gotten from RCA (1301 kg/m^3) due to the RCA greater porosity owing to adhered mortar (Fig. 1c). However, the bulk density obtained for all the aggregate type used were within the values of 1200 -1760 kg/m^3 specified normal weight aggregates in ASTM C33 (2003).

Table 1: Chemical properties of cement used in the study

Chemical constituents	Percentage composition (%)
SiO_2	19.02
Al_2O_3	3.10
Fe_2O_3	4.80
CaO	67.40
SO_3	1.82
MgO	1.48
K_2O	0.35
Na_2O	0.32
TiO_2	0.35
MnO	0.03
BaO	0.16
V_2O_5	0.03
Loss on ignition	1.25

Figure 1: (a) Granite, (b) Gravel and (c) RCA

As presented in Table 2, the granite, gravel and RCA specific gravity were 2.76, 2.66 and 2.53 respectively. Lower specific gravity value for RCA was as a result of the existence of old cement paste on the aggregate units that makes it fewer denser than natural aggregates (Fig. 1c). However, Kervern (2008) suggested that aggregate for high durability PC mixtures should have specific gravity of 2.5 or more. Furthermore, RCA water absorption was higher than that of granite and gravel due to the attached cement paste/mortar. Granite shows the lowest water absorption value 0.30%, followed by gravel (0.45%) and RCA (2.8%)(Table 2). Kevern et al. (2010) suggested absorption of 2.5% or less for high durability PC mixtures.

Table 2 also shows that RCA had the lowest resistance to failure by impact with AIV value of 24.02% followed by 20.08% for Gravel while the best AIV is from granite with 12.19%. The adhered mortar makes RCA less tough thereby result in a greater value of AIV for RCA.

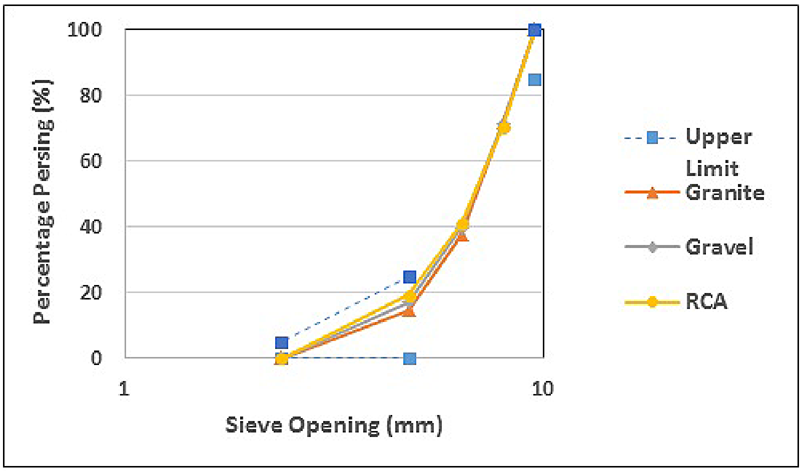

Figure 2: Particle size distribution curve

Table 2: Physical and mechanical properties of aggregates used in the study

Aggregates	Bulk Density (kg/m^3)	Specific Gravity	Water Absorption (%)	AIV (%)	ACV (%)
Granite	1559	2.76	0.30	12.19	19.05
Gravel	1467	2.66	0.45	20.08	21.81
RCA	1301	2.53	2.80	24.02	26.96

However, BS 882 (1992) specified maximum values of 25% for heavy concrete floor finishes, 30% for concrete used in pavement wearing surfaces and 45% for others. This indicates that the aggregate used are strong enough and have good resistance to dynamic load. The values of ACV took the same trend as AIV; there will be a positive correlation between these two characteristics. The test results range from 19.05% for granite to 26.96% for RCA.

Water

Tap water obtained from concrete laboratory was consumed with a fixed water-cement ratio of 0.4 for all mixtures.

2.2 Methods

Three PC mixtures with different aggregate types (granite, gravel and RCA) were carefully prepared and the mix proportions are shown in Table 1. Freshly prepared PC were cast in 100 x 200 mm cylinder moulds to examine hydrologic and compressive strength properties of PC. The technique of compaction adopted for this experiment was that of filling in three layers applying 16 mm diameter steel rod (25 drops) and a 2.5kg standard proctor hammer (10 drops) for all mixtures. Water-cement ratio of 0.4 was used for all mixtures. All specimens were cured for 24 hours in the laboratory immediately after casting before being removed and cured in water for 7, 28 and 56 days. Average of three specimens were taken as the result of each property evaluated.

Table 3: Mix Proportions

Aggregate Type	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
Granite	390	1563	156
Gravel	368	1474	147
RCA	331	1324	132

Volumetric method was picked up to determine the porosity of PC based on ASTM C1754 (2012). Permeability of PC was obtained by the apparatus shown in Fig. 3 in agreement with

Nguyenet al. (2013). The compressive strength was measured according to ASTM C39 (2015). The test setup for compressive strength testing is shown in Fig. 4.

Figure 3: Permeability apparatus

Figure 4: Compressive strength test setup

3 Results and Discussion

Fresh and Hardened Density

Fig. 5 shows the result of density of PC mixtures made with different aggregate type. It could be observed that granite PC had the highest value of both fresh and hardened density followed by gravel and RCA PC. The fresh density valuesfor granite, gravel and RCA PC were 2153, 1999 and 1767 kg/m^3 respectively while hardened density values were 2129, 1981 and 1749kg/m^3 respectively. Tennis et al. (2004) stated that density of PC is in the range of 1600 to 2000kg/m^3.

It is evident from Fig. 5 that hardened density values were found lesser than fresh density for each aggregate type as anticipated. The hardened density of RCA PC was found to be 18% lower than granite PC and 12% lower than gravel PC. This could be due to presence of adhered mortar in RCA. Besides, density of RCA was obtained to be much lesser compared to that of granite and gravel (Table 2) and this resulted in a lower density for RCAPC. Likewise, gravel PC has a lower hardened density (7%) compared to granite PC since gravel aggregate possess lower unit weight.

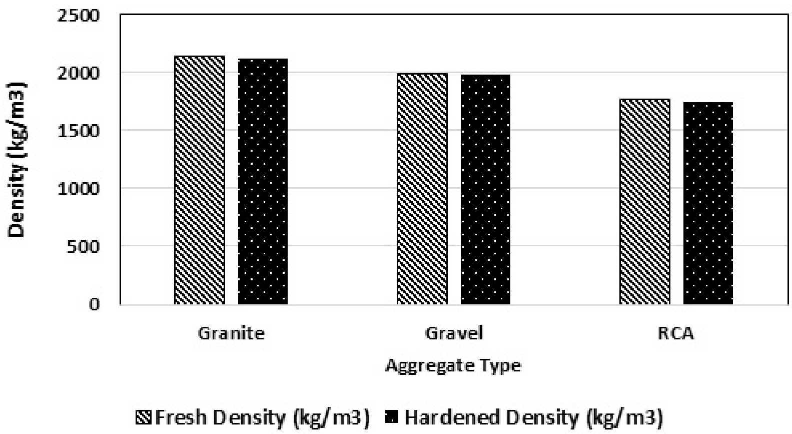

Figure 5: Densities of PC mixtures

Porosity

Porosity is the amount of the overall exposed space within the PC. Fig.6 presented the porosity of all studied PC mixes.It could be observed that RCA PC has the maximum value of porosity, next to it is gravel and then granite PC. The porosity values for granite, gravel and RCA PC was 20.1, 21.5 and 24.3 % respectively. Characteristic porosity for PC ranges from 18 to 35% (ACI, 2010 & Tennis et al., 2004).

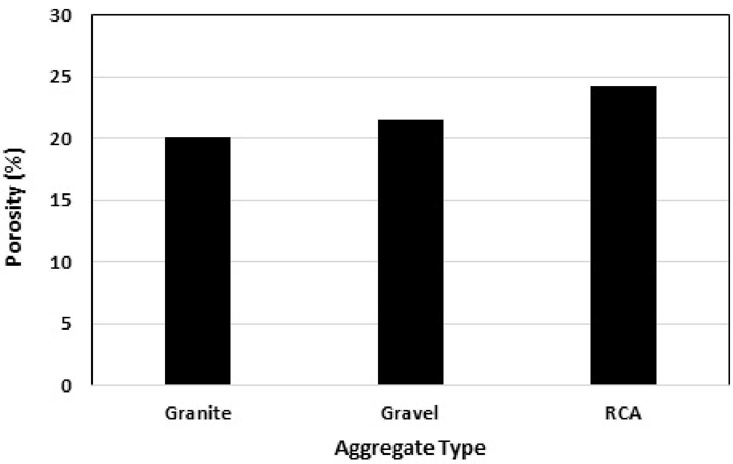

Figure 6: Porosity of PC mixtures

It could also be observed that porosity of PC specimens increases with decrease in unit weight of concrete as well as unit weight of aggregate. Porosity rises as the density of PC declines (Yap et al., 2018; Wang et al., 2006). Porosity of RCA PC is 11.5 and 17.3 % higher than gravel and granite PC respectively. Highest porosity obtained from RCAPC might be due to the porous nature of adhered cement mortar originated from old concrete.

Permeability

Fig.7 shows the permeability of PC mixtures. It was observed that permeability of PC increase as porosity increase for all type of aggregate. This is in agreement with Barnhouse and Srubar (2016) and Yap et al. (2018). Furthermore, permeability of PC increase with increase in water absorption capacity of aggregates. RCA with highest water absorption capacity has the highest permeability. The highest permeability of RCA PC might also be owing to the porous nature of adhered mortar on RCA (Fig. 1c).

The achieved permeability values were 4.7, 4.8 and 8.6 mm/s for granite, gravel and RCA PC respectively which is similar to the obtained 2 to 12mm/s reported by Tennis et al. (2004).

Compressive Strength

Compressive strength of PC samples prepared with granite, gravel and RCA at 7, 28 and 56 days are shown in Fig. 8.As expected, the compressive strength of PC continued to develop with age irrespective of aggregate type. Granite PC specimens recorded the highest strength of 10.2, 12.2 and 13.5 N/mm^2 at ages 7, 28 and 56 days correspondingly. Compressive strength of 9.9, 11.4 and 12.7 N/mm^2 were respectively obtained for gravel PC at 7, 28 and 56 days while RCA PC samples had the least strength with 7, 28 and 56 days strength being 5.7, 6.4 and 8.3N/mm^2 respectively.

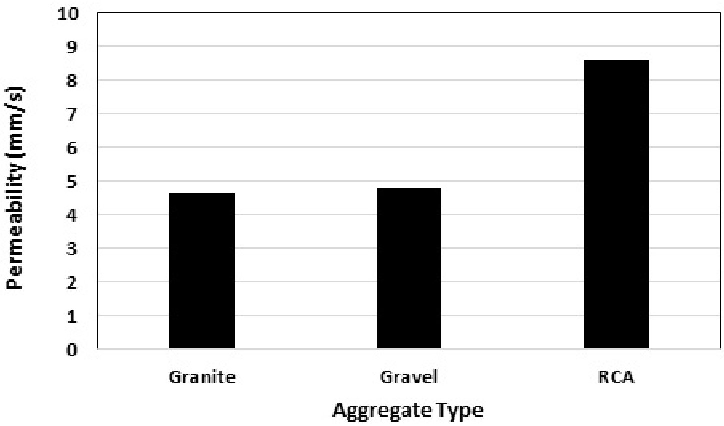

Figure 7: Permeability of PC mixtures

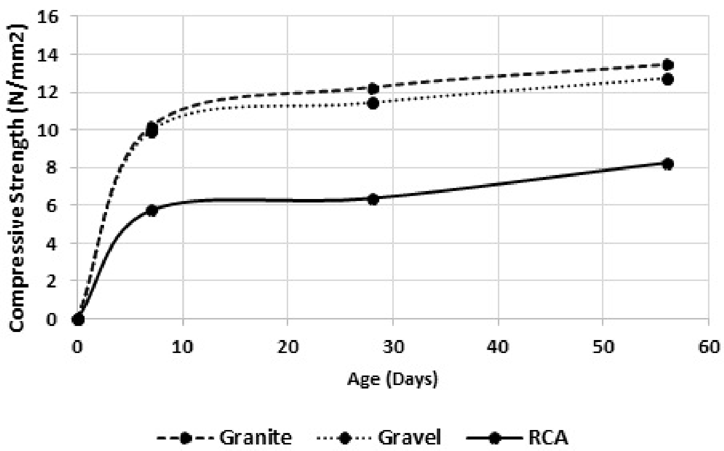

Figure 8: Compressive strength of PC mixtures

Granite PC had compressive strength which is 6.6% and 47.5% higher than gravel and RCA PC at 28 days respectively. The higher strength of granite PC as compared to gravel PC could be due to its rough surface and angular shape (Fig. 1a) which generate a higher surface-to-volume ratio and a stronger bond among the paste and aggregates. The rounded particles and smooth surface of gravel (Fig. 1b) might affect proper interlock of aggregate during compaction which lead to a reduced strength than granite PC. The lower compressive strength of RCA PC was as a result of the presence of weak already cured mortar on the aggregate particles (Fig. 1c). Similar findings were reported by Crouch et al., (2006), Lain and Zhuge (2010), Barnhouse and Srubar (2016) and Yap et al (2018).

Furthermore, the variation in strength can be explained by failure of PC samples (Fig. 9). It was seen that bulk of failures for granite and gravel PC samples occurred in the hardened cement paste rather than within the aggregates (Fig. 5a and b). Though the fractures through the aggregates were greater in gravel PC compared to granite PC. However, more fractured aggregate particles appeared in RCA-PC than others (Fig. 5c). This mode of failure can be attributed to aggregate strength. Aggregates with higher mechanical strength (Table 2) produces PC of higher compressive strength. This is in agreement with Lain and Zhuge (2010).

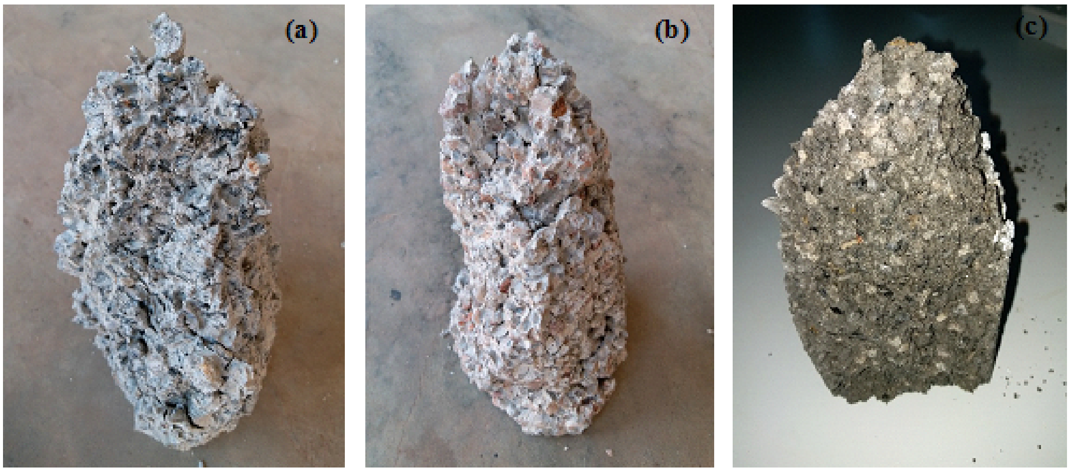

Figure 9: Pervious concrete crushed samples (a) Granite PC (b) Gravel PC (c) RCA PC

4 Conclusion

Experimental investigation has been carried out to evaluate the effect of aggregate type on PC production. Three types of aggregate (granite, gravel and RCA) were utilized and the effects of their properties were studied. Results showed that PC made from RCA has the highest porosity and permeability as well as lowest density and compressive strength owing to the presence of adhered mortar on RCA. The Porosity of RCAPC is 11.5 and 17.3 % higher than gravel and granite PC while its permeability is 44.2 and 45.4 % higher than gravel and granite PC respectively. However, highest density and compressive strength was obtained from granite PC followed by gravel and then RCA PC. Granite-PC had hardened density which is 7% and 18% higher than gravel and RCA PC while its compressive strength is 6.6% and 47.5% higher than gravel and RCA PC at 28 days respectively. It is concluded that aggregate types have significant effect on PC properties.

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