The Characteristics of Pervious Concrete with Gravel as Coarse Aggregate

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Abstract- Pervious concrete is a low-cost and effective drainage technique for metropolitan areas that reduces storm water flow. The goal of this research is to examine the properties of gravel as a coarse aggregate material in pervious concrete. The geotechnical properties of the gravel were investigated to determine their suitability in the construction of pervious drainage structures. The samples collected were subjected to particle size distribution test, aggregate crushing value test, and aggregate impact value test. The concrete samples were then put through a series of tests, including a slump test, a compressive strength test, a density test, and a permeability test. In accordance with the particle size distribution result, the gravel is properly graded. The slump test affirms that as the aggregate size of the pervious concrete reduces, the workability improves. Coarse aggregate of 13.2mm size, had highest compressive strength (4.889KN/m^3) at 28days while those of 19.00mm, 25.00mm, and 37.50mm had compressive strength of 4.520KN/m^3,4.146KN/m^3 and 4.074KN/m^3 respectively. The 37.50mm aggregate size had a higher permeability value compared to that of the 13.20mm aggregate size pervious concrete. The compressive strength increased from 3 to 28 days, for the four aggregate sizes. It was detected that the 37.50mm aggregate size produced pervious concrete with a higher co-efficient of permeability of 8.652 X 10^{-4} cm/sec for aggregate sizes of 13.20mm, 19.00mm, and 25.00mm were 6.845 X 10^{-4} m/s, 5.768 X 10^{-4} m/s, and 3.993 X 10^{-4} m/s respectively. From the analysis of result derived, it is deduced that the use of granite for pervious concrete is stronger than gravel. Gravel can excellently be used in areas that are not subjected to repeated heavy loads.

Keywords- Pervious Concrete, Granite, Gravel, Permeability, Compressive Strength

1 Introduction

Pervious concrete is a porous concrete paving material that allows rain and stormwater runoff to percolate through it or rather flooding the surrounding area. This prevents runoff water from causing erosion downstream in cities, as well as breaking the cycle of water treatment plants required to handle stormwater in towns with combined sewer and storm water systems. This often avoids the need for detention/retention ponds, saving money on construction, safety, and maintenance. (Ajagbe et al., 2018). Conventional concrete-making components, such as cement, gravel, water, and other material, can be used to make pervious concrete. (Tennis et al., 2004).

Pervious concrete is an important component of sustainable construction and also a groundwater recharge strategy. It has earned widespread acceptance as a pavement material in low-volume road applications in recent years due to its environmental advantages. (Rajasekhar et al., 2016). Compared to conventional concrete, it provides a number of advantages in terms of performance and gives the following benefits which are environmentally friendly.

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Benefits include minimizing the risk of flooding, specifically in urban areas, refilling the groundwater level and reducing road puddles. Also, using percolation to improve water quality, sound absorption, heat absorption and assisting in the growth of vegetation. In contrast, it has some weaknesses, such as low strength due to high porosity, requires a lot of maintenance and only appropriate for limited use as a weight bearing unit owing to its strength. A simple solution to preventing natural water infiltration into the soil is to stop constructing impervious surfaces. Instead of using convectional concrete, we should use porous pavement, which has the inherent durability while holding stormwater runoff and refilling local waterways.

Over the years, water, cement, and granite as coarse aggregate make up the pervious concrete that is being constructed. In this article, gravel, which is made up of unconsolidated rock pieces with a wide particle size ranging from granules to boulder-sized fragments according to world production (2009), is used as coarse aggregate. This helps in determining the physical and mechanical properties, as well as evaluating the performance of pervious concrete in which locally sourced gravel from Ogbomoso south west was used as coarse aggregate.

2 Materials and Methods

2.1 Materials

The gravel samples were taken from an existing borrow pit in Egbeda Ogbomoso. Ordinary Portland Cement (OPC) was used according to BS 12:1996, and the portable water was supplied from the laboratory. The materials were subjected to the following tests: sieve analysis, Aggregate Impact Test, Aggregate crushing value, while slump test, compressive strength test, density test and permeability test were also carried out in order to investigate the structural properties of the materials.

2.2 Mix Design

The above tests were repeated on gravel of different sizes, such as 37.5mm, 25mm, 19mm, and 13.2mm as aggregate and cement mix ratio of 1:6 so as to examine the performance of pervious concrete made from locally sourced gravel.

2.3 Materials Characterizations

2.3.1 Sieve Analysis of Coarse Aggregate

The coarse aggregate is subjected to this type of test in line with BS 812: Section 103.1 1989. The total weight of all material larger than each sieve size was calculated and divided by the total sample weight to get the percent retained for that sieve size, which was then removed from 100% to get the percent passing that sieve size.

$$C_{u} = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_{c} = \frac{(D_{60})^2}{D_{10} \, X \, D_{60}} \quad (2)$$

Where:

Cc = Coefficient of Curvature,
Cu = Coefficient of Uniformity,
D10 = Effective size of the largest size of the smallest 10% of soil passed,
D60 = Effective size of the largest size of the smallest 60% of soil passed,
D30 = Effective size of the largest size of the smallest 30% of soil passed

2.3.2 Aggregate Impact Value (A.I.V)

This test was performed in line with BS: 812-112 (Part 2)-1995 to determine the aggregate impact value of coarse aggregates. The impact testing equipment was the apparatus used in evaluating the aggregate impact value of coarse aggregates which follows BS 2386 (part IV) standard. A cylindrical metal measure of 75mm in diameter and 50mm depth, BS sieves in sizes 12.5mm, 10mm, and 2.36mm. An oven, a tamping rod with a circular cross section of 10mm and a 230mm length rounded on one end, and a 230mm length and 10mm circular cross section tamping rod, and a circular cross with 25 tamping rod strokes, the impact testing machine's cup was tightly positioned on the base of the test sample and was crushed with 25 tamping rod strokes.

$$AIV = \frac{Wt\ of\ the\ portion\ passing\ the\ aggt\ sieve\ size}{Total\ wt\ of\ the\ dry\ sample} X100 \quad (3)$$

2.3.3 Aggregate Crushing Value (A.C.V)

The crushing value which is the relative measure of resistance to crushing that can be used to estimate the hardness of an aggregate under a gradually applied compressive force. The following equipment was used: steel cylinder with a plunger and base plate, with a nominal internal diameter of 150mm. A tamping rod with a 16mm diameter and a 600mm length. British standards specify sieves with diameters of 14.0mm, 10.0mm, and 2.36mm. A compression testing machine with a force capacity of 400kN. The apparatus' cylinder was filled with three layers, each of which was tamped with 25 blows of a tamping rod in line with BS 812-110: (Part 3)-1990. The aggregates weight was estimated with a smoothed aggregates surface, and the plunger was inserted. In order to obtain a 40KN load in 10 minutes, the equipment was placed into the compression testing machine at a constant pace. The load was then released, and the crushed materials were removed. The sample was sieved with a 2.36mm IS Sieve, and the quantity that passed was weighed. The formula 4 below was used to calculate the aggregate crushing value.

$$ACV = \frac{\text{Wt of portion passing the aggt sieve size}}{\text{Total wt of Dry sampl}} X\ 100 \quad (4)$$

2.4 Structural Investigations

2.4.1 Slump Test

Concrete slump test as outlined in [BS EN 12350-2: 2009], is a test for evaluating the workability of fresh concrete. Two processes which are batching and mixing must be carried out before the slump test can be accomplished. Batching by volume was considered for the mix ratios 1:4 and 1:6. The coarse aggregate and cement were mixed with portable water. The slump test procedure entails the following steps: Three layers of concrete were poured into the cone, each compacted with 25 tamps of tamping rod. The concrete was now allowed to droop under its own weight while the cone was steadily raised, using the upturned cone and slump rod as a guide, and the slump was then measured.

2.4.2 Compressive Strength Test

The compressive strength of concrete cubes is determined according to BS EN 12390-3:2002. The proportions and materials used to create these test specimens are the same as those observed in the lab. The curing process began after the concrete had been properly mixed and batched. These test specimens were marked and removed from the moulds and kept submerged in clear fresh water until they were taken out for testing after being stored in moist air for 24 hours. After a certain number of days of healing (7, 14, 21, and 28 days). When the specimen was placed in the machine, the weight was applied to the opposing sides of the cube cast. The load was increasingly applied without shock and at a constant rate of 140kg/cm2/minute until the specimen failed. And the maximum load was recorded.

$$\text{Compressive strength of pervious concrete} = \frac{\text{Crushing load (KN)}}{\text{Area of cube (m2)}} \quad (5)$$

2.4.3 Density Test

This test was carried out in accordance to BS EN 12390-7: 2009 by measuring the total length, breadth, and height of the pervious concrete cubes. The weight of the pervious concrete cubes was measured in order to determine the weight/mass of the cube. The weight/mass of the pervious concrete cube will be divided by the volume of the cube to determine its density. The density test result is determined by using Formula 6 below.

$$\text{Density} = \frac{Weight\ of\ pervious\ concrete\ cube}{Volume\ of\ pervious\ concrete\ cube} \text{(kg/m3)} \quad (6)$$

2.4.4 Permeability

In line with BS EN 12390-8: 2019, the permeability of pervious concrete was measured using a falling head permeability setup. Allowing water to flow via a connected standpipe which gave the water head. Allowing water to flow into the sample until the water level in the standpipe fell below a particular threshold was used to conduct the test. The water in the standpipe was timed at a 5 second interval, and the test was repeated after the standpipe was loaded and the water level was lower. A pervious concrete sample was tested for permeability.

3 RESULTS AND DISCUSSION

3.1 MATERIALS CHARACTERIZATIONS

3.1.1 Sieve Analysis Results

The great portion of the particle size distribution curve as shown in figure 1 can be seen to be steep. Therefore, it can be inferred that the soil has a particle size distribution extending over a limited range with most particles having a variety of sizes. The soil is said to be closely graded or uniformly graded. The sieve analysis result of the soil meets the British Standard requirement for coarse aggregates under coarse grading soil, hence, it's suitable for use in the construction of pervious concrete. Formulas 1 and 2 above were therefore used to determine the Coefficient of Uniformity Cu and the Coefficient of Curvature Cc, respectively.

From the figure 1; D10 = 2, D60 =25, D30 =9
According to calculations, Cc = 1.62 and Cu = 12.5.
BS1377 (1990): part 2 specifies that: If Cu > 4, then the soil is well graded.

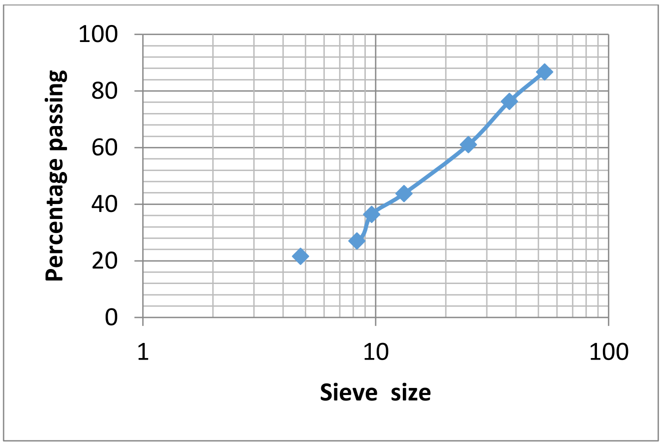

Fig. 1: Particle size curve for the sand used

When a well-graded material is compacted correctly, all of the different sized aggregate particles will position themselves within the entire matrix in such a way that a densely knit layer of maximum density is produced. A well-graded material is better able to carry and disperse load than a badly graded material, and it will be more stable, with pressure or stress distributed uniformly.

3.1.2 Aggregate Impact Value

The aggregate impact value test result in table 2 illustrates that as the aggregate size reduces, the value of the aggregate impact reduces, which is 76.50%, 72.88%, 60.64% and 51.28% for aggregate sizes of 37.50mm, 25.00mm, 19.00mm and 13.20mm respectively. The Aggregate Impact test revealed that toughness is a material's ability to withstand impact owing to traffic loads, in which the stones are subjected to pounding action or impact, with the possibility of the stones shattering into smaller fragments. As a result, the stones should be robust enough to withstand impact. The purpose of the test is to determine the hardness of stones, or the resistance of the fracture to multiple hits.

Using the standards of: > 10 extraordinarily strong, 10–20% strong, 20–30% satisfactory, > 35 weak. As a result, aggregate sizes of 37.50mm, 25.00mm, 19.00mm and 13.20mm are weak. Which invariably implies that the aggregate impact value of gravel is very weak and cannot resist impact due to traffic loads.

3.1.3 Aggregate Crushing Value

From table 3, the result of the aggregate crushing value test shows that the aggregate passing through the sieve (37.50mm) is adequate, but the lesser sieve is weak. The aggregate size decreases with increasing aggregate crushing value, which is 51.9%, 74.8%, 76.0% and 100% for aggregate sizes of 37.50mm, 25.00mm, 19.00 and 13.20mm respectively. The lower the percentage retained on each sieve and the higher the percentage passing through each sieve, the higher the compressive strength. The crushing strengths for sieve sizes of 37.50mm, 25.00mm, 19.00mm, and 13.20mm are 483KN, 540KN, 1052KN, and 1200KN, respectively. The correlation between aggregate sizes and crushing values, on the other hand, will differ depending on the type of specimen utilized. The aggregate sizes used have weak strength due to their high crushing strength, which implies that they are weak in terms of crushing strength. As a result, it's not suitable for the construction of pervious concrete.

Table 1. Result of Aggregate Impact Value

Aggt. Sizes	Mass retained (g)	Mass passing (g)	Total weight of the sample (g)	Aggt. impact in %
37.5	184	599	783	76.50
25.0	211	567	778	72.88
19.2	318	490	808	60.64
13.2	343	361	704	51.28

Table 2. Aggregate Crushing Value

Aggt Sizes	Mass retained (g)	Mass passing (g)	Total wght. of sample (g)	Crushing strength (KN)	AIV (%)
37.5	334	360	694	483	51.9
25.0	234	693	927	540	74.8
19.0	278	878	1156	1052	76.0
13.2	0.00	906	906	1200	100

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3.2 Structural Investigations

3.2.1 Slump Test

The aggregate sizes were being used to conduct the slump tests. Table 3 shows the results achieved. With growing slump, the aggregate size reduces. The workability of pervious concrete increases as the aggregate size of the concrete decreases. The aggregate size of 37.50mm and 25.00mm results in a collapse slump, whereas the aggregate size of 19.00mm and 13.20mm results in a shear slump that is going toward a true slump, indicating its workability.

Table 3. Slump test result for mix ratio 1:6

Aggregate Size	37.50	25.00	19.00	13.20
Slump (cm)	16	18	22	25

3.2.2 Compressive Strength Test

Table 5 shows the compression test results for 3, 7, 14, 21, and 28 days. On the 28th day, size 37.50mm had a compressive strength of 4.074N/mm2. The result is much lower compared to others due to larger pore spaces with rough surfaces, which reduce their compressive strength. Due to the tiny sizes of aggregates, which minimizes the percentage of pore space in the pervious concrete, the compressive strength of the concrete improved rapidly, culminating in a high strength of particle size 13.20mm with compressive strength of 4.889N/mm2 at 28 days, as shown in figure 2.

3.2.3 Density Test

Pervious concrete aggregate size 13.20mm increases from 1.82g/cm3, 1.88g/cm3, 1.93g/cm3, and 1.98g/cm^3. For 19.00mm ranges from1.88g/cm3, 1.87g/cm^3, 1.99g/cm3 and 2.01g/cm^3. This shows that cubes are adequate in terms of density, since the compressive strength is the determining factor for flexural member, its value has an overriding influence on that density. The formation of produced hydration products in the pore structure of hardened cement pastes caused the density to gradually increase cure time (Hewlett, 1998). The readings were higher than the minimum of 1500kg/m^3. The cubes' net volume is 0.03375m^3.

3.2.4 Permeability Test

For different aggregates sizes of 13.20mm, 19.00mm, 25.00mm and 37.50mm with water- cement ratio of 0.6. The rates of 13.20mm and 19.00mm are limited by the sizes of the aggregates and the amount of the cement that has being able to fill the pores, which had collected in the base of the cylinder as shown in table 4 below. Higher compaction energies result in a higher density and a lower permeability rate. Sizes 25mm and 37.50mm indicate increase in permeability due to the presence of larger voids.

Table 4. Showing the average permeability rate

Size(mm)	Water-cement Ratio	Weight. of cylinder and concrete (wet)	Average Permeability rate (mins)	Coefficient of Permeability K ($x10^{-4}$ m/s)
13.2	0.6	7.18	0.52	3.993
19.00	0.6	7.20	0.39	5.768
25.00	0.6	6.82	0.30	6.845
37.50	0.6	6.30	0.24	8.652

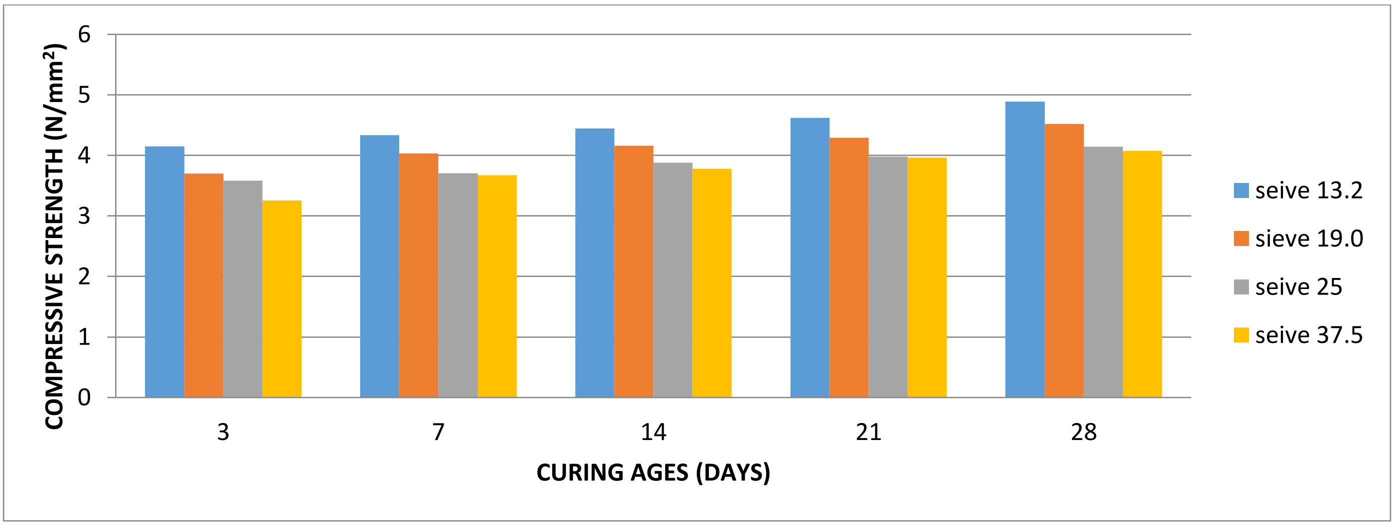

Fig. 2: Pervious concrete's combined compressive strength at various curing ages (Days)

4 Conclusion

The test results showed that gravel has a good distribution of all aggregate sizes. The lower the aggregate size, the higher the compressive strength, and the lower the permeability. Gravel also has low impact value and low crushing strength. Hence, gravel of size 13.2mm as coarse aggregate is suitable for pervious pavement construction, and is best used for parking areas with low traffic, residential streets and pedestrian walkways.

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