SELECTION OF AGGREGATE SUITABLE TO PRODUCE PERVIOUS CONCRETE FOR SUSTAINABLE BUILT ENVIRONMENT

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Abstract

Pervious concrete is a tailored concrete to have very high water permeability. The presence of interconnected pores of different sizes and shapes allow the passage of water to flow through easily. Permeable concrete pavement was shown to have significant advantages in storm water management over impervious pavements and minimizing the risk of flooding in urban environment.

This research was conducted to determine a suitable aggregate for pervious concrete. The research methodology involved substituting the conventional crushed rock coarse aggregate with the three types of materials such as Recycled Concrete Aggregate **(RCA),** River Gravel **(RG)** and Gravel collected from Cinnamon Estates (**CEG)** in different percentages in order to determine the optimum percentage of materials that can be added. These materials are directly substituted for the coarse aggregate at 0%, 15%, 30%, 50% and 100% of the virgin material. Likewise three specimens are done, for RCA, RG and CEG with each consist of five batches. The performance of pervious concrete was evaluated through strength development, void content and permeability. The relationships between strength and void content, and permeability and porosity were reported. It was found that the recycled concrete aggregate affect the compressive strength of pervious concrete without influencing the permeability.

Keywords: River gravel, recycled concrete aggregate, compressive strength, permeability, porosity

1. Introduction

Regular flooding in many cities in several countries is not uncommon during the rainy season. Impervious surfaces, resulting from infrastructure construction due to increased urbanization, block the infiltration of natural rainwater to the ground and increase the storm water runoff. Due to rapid development, land conservation is getting increased day by day which will cause to be a problem of allocating space for drain construction. With the absence of sufficient drainage flash flooding becomes inevitable.

Pervious concrete pavements can be used for the construction of secondary roads, parking lots, driveways, walkways, sidewalks and greenhouses(Figure 1). It is an important application for sustainable construction. Because, pervious concrete reduces the runoff from paved areas, which reduces the need for separate storm water retention ponds and allows the use of smaller capacity storm sewers. This allows property owners to develop a larger area of available property at a lower cost. Pervious concrete also naturally filters storm water and can reduce pollutant loads entering into streams, ponds and rivers. Pervious concrete functions like a storm water retention basin and allows the storm water to infiltrate the soil over a large area, thus facilitating recharge of precious groundwater supplies locally. All of these benefits lead to more effective land use.

(a) Pedestrian pavement ***(b) Car park***

Figure 1: Pervious concrete application

Pervious concrete can also reduce the impact of development on trees. A pervious concrete pavement allows the transfer of both water and air to root systems allowing trees to flourish even in highly developed areas.

In previous studies the design parameters of pervious concrete have been investigated such as water cement ratio, material size, fine aggregate content, etc. Joung (2008) has investigated concrete mixes containing three different gradations of coarse aggregate. Further found that the typical coarse aggregate size for the pervious concrete was ranges from 9.5 to 19 mm. All concrete samples tested in this study had a w/c of 0.3. Rizvi et. al. (2009) studied the incorporating Recycled Concrete Aggregate (RCA) into pervious concrete to create a very sustainable concrete product for paving. The research methodology involved substituting the coarse aggregate in the pervious concrete mix design with 15%, 30%, 50% and 100% RCA. From their finding, it was found that the 15% RCA shows similar behaviour to the control in compressive strength. Sriravindrarajah et. al. (2010) reported that the Performance of pervious recycled aggregate concrete with reduced cement content. Murao et. al. (2002) reported that at a given porosity, the pervious concrete with recycled concrete aggregate showed significantly reduction in strength compared to the control concrete with natural aggregate.

In order to improve the environmental sustainability, this research was trying to determine the suitable material for pervious concrete. So, three types of materials such as recycled concrete aggregate (RCA), river gravel (RG) and gravel collected from cinnamon estates (CEG) were used to substitute in different percentages with virgin coarse aggregate. The performance of pervious concrete was determined by testing compressive strength, void content and permeability.

2. Methodology

This research looked at substituting three types of materials, namely, Recycled Concrete Aggregate (RCA), River Gravel (RG) and Gravel collected from Cinnamon Estates (CEG) with the virgin coarse aggregate in different percentages in order to determine the optimum percentage of materials that can be added. The material was directly substituted for the coarse aggregate at 10%, 15%, 30%, 50% and 100% of the virgin material. The RCA that was used for this research comprised crushed and sieved concrete of demolished slabs and beams.

The mix design details are illustrated in Table 1. As indicated in the Table 1, for each percentage substitution 0.3 was used as water cement ratio and fine aggregate content was 10% from the total aggregate content. For specimens, 150*150*150 mm size cubes and 150 mm height 110mm diameter cylinders were used. Then a total of 18 Nos. of cubes and 6 Nos. of cylinders were cast for each of the 6 batches.

The cast cubes and cylinders were demoulded 24 hours after casting and they were set to cure in moist conditions for a maximum of 28 days. Then the samples were tested for compressive strength, void content, and permeability.

Table 1: Mix details for the pervious concrete mixtures

Material Type	*River Gravel / Recycled Concrete Aggregate/ Gravel from Cinnamon Estates*					
Percentage replacement (%)	*0*	*10*	*15*	*30*	*50*	*100*
w/c Ratio	*0.3*					
Fine Aggregate (%)	*10*					
Nominal aggregate Size (mm)	*9.5-12.5*					
Compaction	*15 s External Vibration*					
Casting	*1 Lift*					

3. Sample preparation

The materials that were used for the research were successively sieved in order to obtain the aggregate that was passing from 12.5mm sieve and retained on the 9.5 mm sieve. Before batching sieved RCA, it was saturated with water for 24 hours to ensure that the mortar in the RCA does not absorb a large amount of water in mixture.

The nominal minimum road pavement thickness is 150mm.Therefore, 150mm*150mm*150mm cubes and 150mm height cylinders were cast. The cubes and cylinders were cast in 1 lift and vibrate externally within 15 seconds. Figure 2 shows the pervious concrete samples cast with three different materials.

(a) Cube cast with Cinnamon estate gravel

(b) Cube cast with recycle concrete aggregate

(c) Cube cast with river gravel

Figure 2: Pervious concrete samples

4. Testing procedure

The concrete cubes and cylinders were cured for 28 days and samples were tested for the compressive strength, void content and permeability.

4.1 Compressive Strength Testing

Samples were tested for compressive strength at 7, 14 and 28 days. The samples were cured until they were tested.

The compressive strength of concrete was investigated by using the concrete cracking machine. The size of 150*150*150 mm concrete cubes was used. This test was carried out according to the BS 1881: Part 121:1993 standarded.

4.2 Void Content Testing

The void content of pervious concrete was calculated by using the difference of weight between the air dry sample and the saturated sample under water. Equation (1) was used in this test (Park and Tia, 2004).

$$V = \left[1 - \left(\frac{W2 - W1}{\rho w * vol}\right)\right] * 100\% \qquad (1)$$

Where *V* is the total percent air void content, W_1 is the mass of the saturated sample, W_2 is the mass of the oven dry sample, *Vol* is the volume of the sample, and ρ_w is the density of water.

4.3 Permeability Testing

The permeability of pervious concrete mixtures was determined using the falling-head permeability test apparatus. The coefficient of permeability (*k*) was determined applying Equation (2).

$$k = \frac{aL}{At} * log\left(\frac{h1}{h2}\right) \qquad (2)$$

Where *k* is the coefficient of water permeability, *a* is the cross-sectional area of the standpipe, *L* is the length of the sample, *A* is the cross-sectional area of the specimen, and *t* is the time for water to drop from level h_1 to h_2 (Das, 1998).

Figure 3: Permeability Apparatus

5. Result and Discussion

Table 2 shows the compressive strength of concrete in control sample and other mixes at the ages of 7, 14 and 28 days.

Table 2: Compressive strength for the pervious concrete mixtures

Percentage (%)	***Compressive strength (MPa)***								
	7- day			***14- day***			***28- day***		
Control (0)	*28.52*			*30.71*			*45.89*		
	RG	***RCA***	***CEG***	***RG***	***RCA***	***CEG***	***RG***	***RCA***	***CEG***
10	*26.56*	*25.46*	*25.01*	*29.5*	*27.42*	*29.01*	*42.4*	*39.21*	*32.54*
15	*13.47*	*25.21*	*26.21*	*28.58*	*29.26*	*27.28*	*42.5*	*40.19*	*31.85*
30	*12.98*	*19.23*	*17.39*	*37.84*	*25.15*	*19.51*	*34.39*	*36.22*	*19.27*
50	*11.82*	*20.14*	*19.21*	*26.58*	*27.05*	*19.48*	*33.34*	*31.6*	*16.25*
100	*10.17*	*17.07*	*12.96*	*28.38*	*23.85*	*13.85*	*27.43*	*24.79*	*13.93*

Note: RG: River gravel, RCA recycled concrete aggregate, CEG: gravel collected from cinnamon estates

For a concrete mix at the same age, the compressive strength of 15RG and 15RCA had very similar strengths to the control samples (Figure 4). But, the compressive strength of 15CEG is quite lower than the control sample. On the other hand, at 30 % replacement and higher there was a significant decrease in compressive strength.

Figure 4 shows the 28 day compressive strength of three materials. Here, RG and RCA shows similar strength but quite high in RG in each test specimen. Further it shows that 10% and 15% RCA samples are same in compressive strength. The compressive strength reduction of 10% RCA sample and 15% RCA sample with the control sample was 14.56% and 12.42% respectively. But in 30%, 50% and 100% samples, the compressive strength reduction is relatively high.

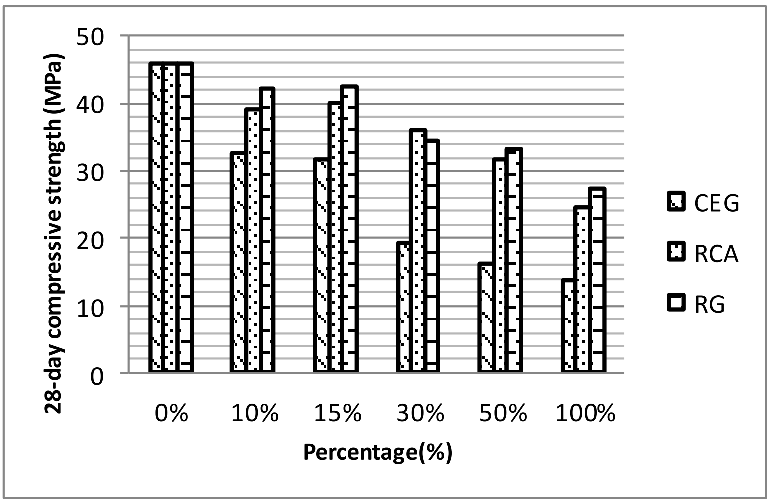

Figure 4: 28-day compressive strength for three materials

The void content of the 15RCA sample and 15 RG sample was very similar to the control sample at 12.06%, 11.82%, and 10.31%respectively,but in 15CEG sample it's quite high such as13.64% (Figure 5). Void content is slightly increased with the increment of RCA percentage in the concrete unit.10% and 15% RCA replacement show 12% of void content.

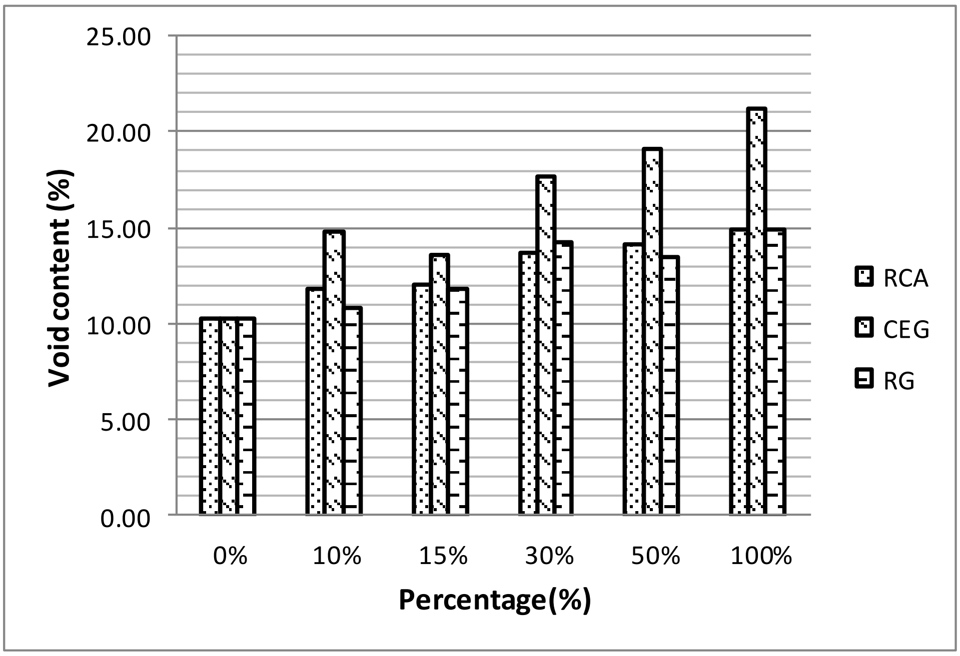

Figure5: Void content of material

The void content for the 30%, 50% and 100% samples was significantly higher than 15%. Some of the increased void content can be attributed to the increase in the percentage of the highly porous RCA, RG and CEG. However, most of the change in void content was due to the different bonds that were formed between the substituted material and the virgin material, and the greater percentage of coarse material in the mix as the substituted material content increased. This difference was not evident up to a replacement percentage of 15%.

Figure 6 shows permeability variation of three materials in different percentages. The permeability results also clearly showed the different bonding properties of the substituted material. Here also the 15RG and 15RCA samples had very similar permeability results compared to the control samples. The both RG and RCA samples show similar permeability values for each percentage separately. Once again 15CEG sample shows quite high permeability than the control sample.

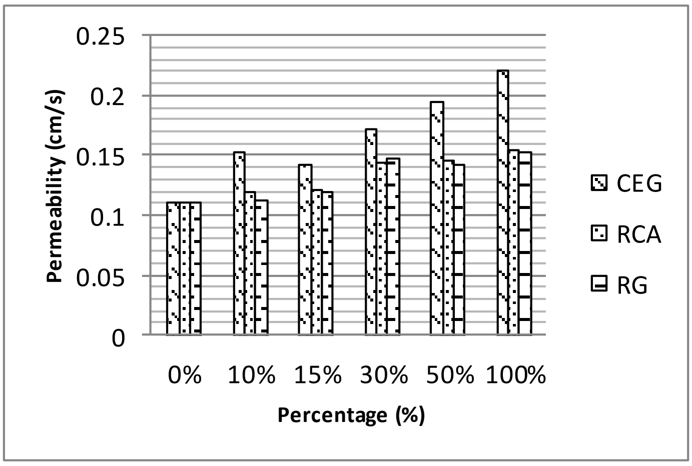

Figure6: Permeability of three materials

The other samples such as 30%, 50% and 100% again had significantly higher permeability rates than the control samples. But, such high rates of permeability have an adverse effect on the compressive strength of the samples and therefore decrease the load bearing capacity.

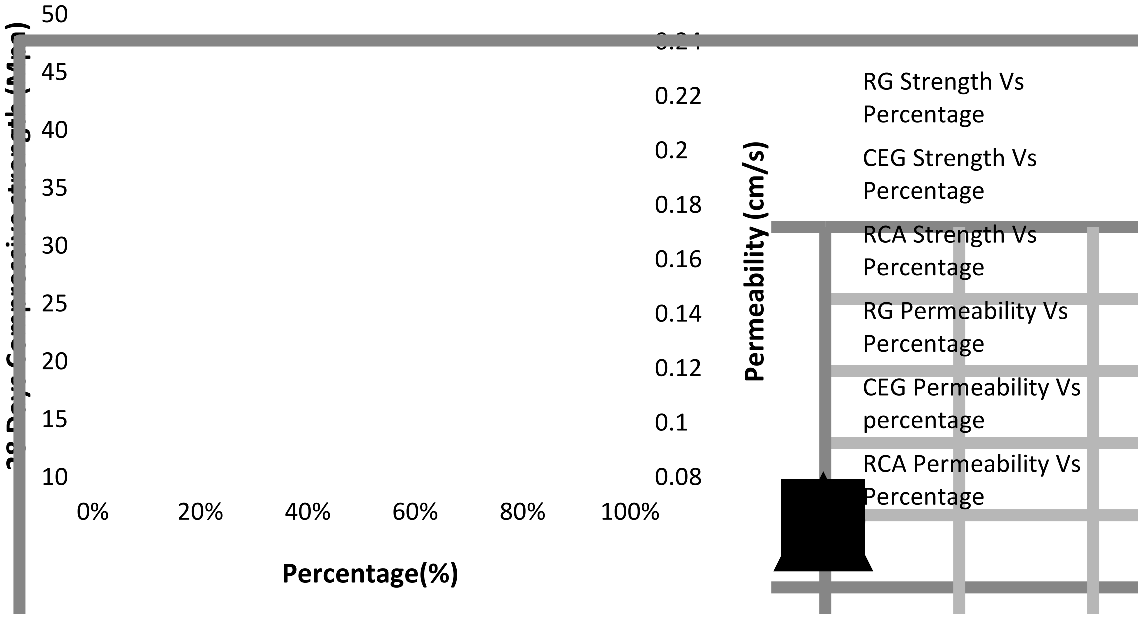

Figure7: Relationship between strength and permeability for pervious concrete

Figure 7 shows the empirical relationships between strength and permeability for pervious concrete as a function of the aggregate type and percentage mix. From this plot, it is possible to estimate the strength and permeability of cinnamon estate gravel, river gravel and recycled concrete aggregate pervious concretes for a given percentage. These relationships could be used in determining the suitable material for the pervious concrete to satisfy both strength and permeability requirements for a given percentage. At 15%, RG sample shows high compressive strength than the RCA sample. But, permeability is high in pervious concrete with RCA than with RG at 15%.

6. Conclusions

The purpose of this research was to find out suitable aggregate for pervious concrete to make pervious concrete an even more environmentally sustainable option by introducing three materials such as Recycled Concrete Aggregate **(RCA),** River Gravel **(RG)** and Gravel collected from Cinnamon Estates (**CEG**) in to the mixture. This research evaluated substituting the virgin aggregate with five different percentages of each material. Six batches of concrete were mixed for each material and these included the control mix, 10%, 15%, 30%, 50% and 100%. Three cubes and one cylinder were cast for each of the five batches for the each material type.

Hardened concrete tests were also done on the samples and these included compressive strength, void content and permeability. Three samples were tested for each mix at 7, 14 and 28 days. The 28day strengths were considered to be the final cured strength for each of the mixes. The 15% samples had very similar strengths to the control samples. On the other hand, there was a significant decrease in strength for the 30%, 50% and 100% samples. The void content and permeability of the 15% samples was very similar to the void content and permeability of the control samples. The 30%, 50% and 100% samples had a significant increase in void content and permeability from the control samples.

When the aggregate percentage is above 30%, the drainage capacity of the pervious concrete is gradually increased but the compressive strength of the pervious concrete is gradually decreased. The 15% sample did not significantly affect any of the parameters when compared to the control mix of pervious concrete. It was determined that the optimum replacement percentage for material in to pervious concrete is 15% as it does not significantly affect the pervious concrete. Although the compressive strength of RG is greater than RCA the difference is not much high.

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