Compressive Strength and Infiltration Characteristic of Pervious Concrete Using Recycled Concrete Aggregate

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Compressive Strength and Infiltration Characteristic of Pervious Concrete Using Recycled Concrete Aggregate

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Abstract. In construction industry, rapid development will increase the demand versus supply which leads to increasing the production of construction waste. Recycle Concrete Aggregate (RCA) was proposed as the one of the component in the pervious concrete for sustainability in the construction industry to reduce the wastage. The pervious concrete was function as a medium to allow the water penetrate through porosity of the concrete and avoiding water from pooling at the surface. Therefore, this study is conducted to investigate the properties of the pervious concrete by infiltration test and compression strength test using Recycle Concrete Aggregate (RCA) and Natural Aggregate (NA) as the main composition. The cement aggregate ratio of 1:3 and 1:5 were choosing as variable to produce the workability pervious concrete that similar to conventional concrete. The replacement of NA with RCA is likely a viable option for structural use.

1. Introduction

Concrete is a main material used for any structure in the construction industries. The ability of the concrete to resist load varies depending on its application. The reason concrete is widely used in construction is because it is easy to fabricate it to any shape and structure. The composition of concrete is primarily consisting of water, cement and aggregate that are mixed with varies ratio depending on several factors such as strength and cost consideration. Sand or fine aggregate is also added in the mixture as an element to fill the presence gap between larger aggregate. This conventional concrete is different compared to pervious concrete in terms of the mixture content and usage. The pervious concrete functions as a drainage cover or hardstand pavement by allowing the water to seep between the interconnecting void in it to prevent the water from pooling at the surface.
[1] states pervious concrete requires less raw materials compared to conventional concrete based on composition content of course aggregate and cement paste with little fine aggregate or without fine aggregate.

Generally, both types of concrete require aggregate as a main element in their mixture but it will deal with the issue of source depletion when it comes to the natural resources. Besides that, the construction industry itself produces a tonnes of concrete volume wastes during concrete casting, renovation, repairing, demolition and maintenance. There are a lot of possibilities of excessive

disposal to dumping site due to mishandled wastes during the construction. About 50% from the nature of raw material has been taken consuming 40% of the total energy and 50% of total waste produce for each construction [2]. This problem will lead to inadequate area of landfill and increase the rate of carbon pollutants in the environment. Thus recycling the concrete waste by extracting the aggregate for another use would likely help in minimizing the increasing number of concrete waste and reduce the cost in construction industry. This condition further strengthened by the use of Recycled Concrete Aggregate (RCA) in concrete mixture for reducing the need for opening new aggregates quarries and decreases the amount of construction waste that goes into landfill.

This paper seeks to: (i) compare the compressive strength of pervious concrete using recycled concrete aggregate (RCA) and natural aggregate (NA), (ii) analyse the infiltration rate using recycled concrete aggregate (RCA) and natural

2. Literature Review

Recycled-concrete aggregate (RCA) is one of the ideas for future sustainability in construction industry that can be used for non-structural elements such as drain cover, decoration at park, concrete walkway, pervious concrete and any else than building structure. For United State, RCA was introduced as non-structural basis material [3]. The use of this material in non-structural elements as a filler material or as a base course material of underlying layer for improving soil characteristics has also enabled a reduction in the usage of NA. Some studies on RCA were suggested replacing NA with RCA in structural concrete for non-structural application.

Approximately 10 billion cubic meter of concrete is produced annually and about 60% to 80% of the concrete volume mainly consists of NA [3]. The calculated amount of NA from the annually production, the consumption of the NA is high which cause it depletion and demand at the same time. Recycling of the waste concrete can reduce the uses of NA for non-structural concrete element. A total number of 431 million tons of aggregate was produced in 2008 which was used in the civil engineering field and building industry with percentages of 79% and 21% respectively. About 5 % of 431 million tons is recycling demolition wastes aggregate [4]. Although the production number of RCA is small, but it provides a huge contribution in reducing environmental impact by reducing deterioration of NA. The RCA mechanic properties may be similar to NA of conventional concrete shown by many studies of material made modification. However, RCA has higher absorption of water compared to NA which is caused by old mortar attached to the RCA. In addition, some modifications in the water cement ratio needed in order to have a similar workability of normal concrete.

In United State and Japan, pervious concrete is used for more than 50 years. It is an engineering application to solve engineering problems by using the feature of pervious concrete [5]. Pervious concrete is the concrete that allows air and water to penetrate through porosity of the pervious concrete [6], usually is used to reduce the runoff on top of the surface from precipitation. Pervious concrete has similar constituents as normal concrete. Its total volume consists 15% to 30% of interconnected void network that allows 0.014 to 0.023m3 of water per minute through its open cells for each 0.0929m2 of surface area [7]. These values are larger than the occurrence of the rain and it very effectively can reduce the excessive runoff from heavy rainfall. For special type of pervious concrete, it has large pore proportion range which is between 2 to 8mm and its percentage of porosity is 15% to 30% typically. The water flow easily through the pervious concrete since it is allowed by the present of the large pores interconnected system [8]. Pervious concrete design combination of structural and hydrological for pavement construction to storm water management is the best solution and it manages to receive recognition from the US Environmental Protection Agency recognition. Towards green ecological development, application of RCA is considered as an effective measure in achieving sustainability construction industry development [9].

The major characteristic of pervious concrete that needs to be tested is it strength under compressive load and infiltration rate. Compressive strength of pervious concrete using RCA is weaker than that for the pervious NA concrete [8]. It shows in the Figure 1 that the RCA use to replace the NA in the concrete mixing with percentages of 0% and 30% is almost similar for the 0.25 of water cement ratio.

However, the replacement of 100% RCA in the pervious concrete has resulted in decrease compressive strength about 5N/mm2 [8]. Infiltration characteristic is the main feature of the pervious concrete. The evaluation of the infiltration is on the volume of water per unit time or flow rate of water that can pass through the pervious concrete within the interconnected void. Water penetration through pervious concrete is depending to the air void content [6]. The mix proportion of the pervious concrete will be more challenging in achieving the balance between the acceptable infiltration rates with adequate compressive strength [10].

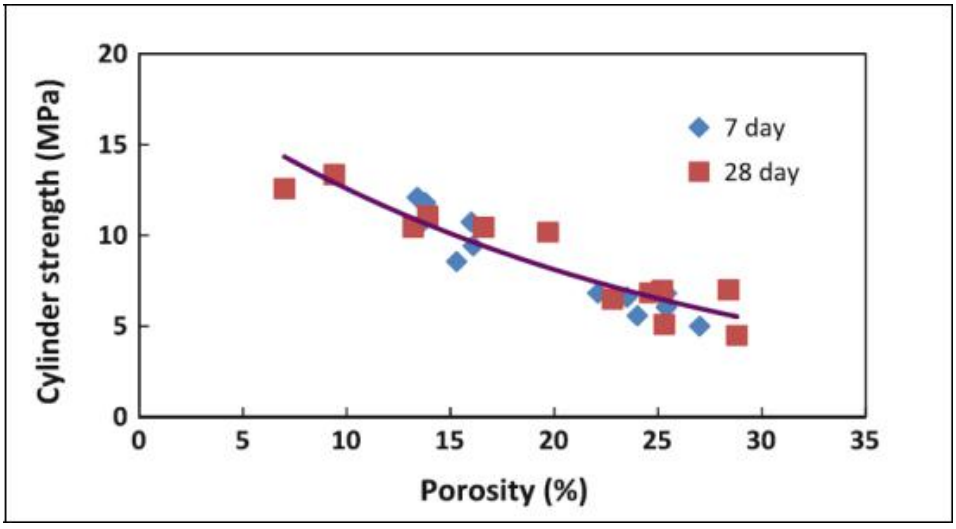


Figure 1. Relationship between strength and porosity for recycled pervious concrete [8]

3. Methodology

Methodology of this research will elaborate on the materials used, the procedure of mixing concrete and the laboratory testing for investigation of compressive strength as and infiltration characteristic as shown on Figure 2. The compressive strength test was conducted using BS EN 12390: Part 3:2009 as a guideline while infiltration test was conducted based on ASTM C 1701 (ASTM 2009) standard.

3.1. Material Selection

In this study, pervious concrete main materials used are Ordinary Portland Cement which follow MS EN 197: Part 1:2007 specifications, coarse aggregate and water. For sampling pervious concrete, fine aggregate or sand was not added to mix design and natural aggregate was used as a coarse aggregate. NA was obtained through supplier whereas RCA was obtained from construction site concrete waste materials.

3.2. Water-Cement Ratio

The water cement ratio is the proportion of the weight of water to the weight of cement that use in concrete mix. The water cement ratio of 0.3 was used in this study to prevent the cement paste settle to the bottom and fill the void. It requires 0.3kg of water for every 1kg of cement used in pervious concrete.

3.3. Concrete Mix Design

Mix design of pervious concrete was prepared into two portions using water, cement and aggregate ratio of 0.3:1:3 and 0.3:1:5. Production of pervious concrete in this study, the system mix proportions for 1 cube and 1 slab:

i. Weight 3kg and 5kg for mix design 0.3:1:3 and 0.3:1:5 respectively of coarse aggregate for both RCA and NA

ii. About 0.3kg of water use for mix design and set as fixed through this study.

iii. Cement required for the mix design is 1kg as fixed.

Concrete density of 2400kg/m^3 is set as fixed value to calculate the mix proportion.

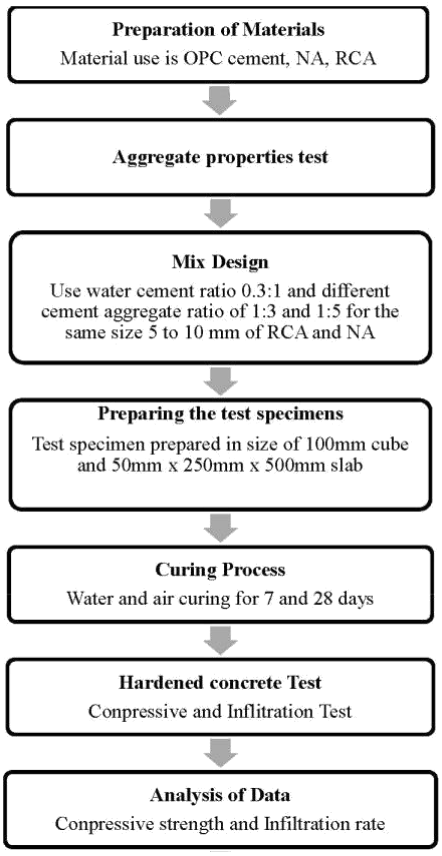


Figure 2. Flow chart of research methodology

3.4. Batching and Mixing

Batching is the process of mix together the water, cement and aggregate done using concrete mixer. The first thing in batching process is the aggregate pour into the mixer and cement little by little. Then water is poured into the mixer while the mixer rotating for 15 minutes until the mortar formed and it depend on the amount of ingredient inserted in the mixer. Lastly, the fresh concrete is casted into the cube and slab mould.

3.5 Casting and Curing

For concrete casting phase, the test specimen prepared in size of 100mm cube for compressive strength test and 50mm x 250mm x 500mm slab mould for infiltration test of pervious concrete. After casting of the concrete, the fresh concrete need to be left for 24 hours before it can be unmould for hydration process taking place. The concrete will be harden and next ready for curing. Curing process in important in order to prevent the moisture loss to allow the concrete gaining it strength. Curing is needed to prevent the moisture of the concrete being hydrated atmosphere that can lead to shrinkage and it will be tested for 7 days and 28 days after casting. Concrete will gain it fully strength at 28 days or curing.

During curing period for hardened concrete, the cube specimen was tested for compressive strength after 7 days and 28 days using Auto Test 3000 compression machine with compression rate 3kN per second. The infiltration test was conducted after 7 days and 28 days using slab specimen with cylindrical pipe-like and slab mould as shown in Figure 3. In this test, the cylindrical pipe-like was placed at two different points on the top of slab before filling with water. The time was taken during pouring the water into the cylindrical. The infiltration rate is equal to the flow rate of the water in

cylindrical pipe-like by calculate the volume of the water divided by time taken to all water flow into pervious concrete.

Figure 3. a) Compression Test for cube specimen, b) Infiltration Test for slab specimen

4. Result and Discussion

4.1 Compressive Strength of RCA and NA Pervious Concrete with Different Cement-Aggregate Ratio
The compressive strength result of RCA and NA pervious concrete using mix design 0.3:1 of water cement ratio and aggregate size of 5mm to 10mm with two different cement aggregate ratios which is 1:3 and 1:5 is shown in Table 1.

Table 1. Pervious Concrete Compressive Strength Data

Water Cement Ratio	Agg. Size (mm)	Type Of Agg.	Cement agg. ratio	Curing (Day)	Compressive Stress (N/mm^2)			Average (N/mm^2)
0.3:1	5-10	Natural aggregate (NA)	1 : 3	7	22.16	23.04	23.67	22.960
				28	28.80	18.91	22.24	23.317
			1 : 5	7	12.610	9.447	12.112	11.389
				28	13.630	13.030	12.120	12.927
		Recycled concrete aggregate (RCA)	1 : 3	7	4.960	6.339	5.993	5.764
				28	6.907	8.181	6.561	7.216
			1 : 5	7	4.430	4.569	3.751	4.500
				28	4.953	4.717	5.148	4.939

Figure 4 shows the interpretation result of compressive strength of RCA pervious concrete and NA pervious concrete with given cement aggregate ratio mix proportions. The pervious concrete with different mix ratio gives a different compressive strength. This characteristic with those factor are same with the normal concrete compressive strength.

Obviously the curing factor were normally known for 28days of curing, the concrete achieve in optimum strength compared to 7 days of curing. The pervious concrete compressive strength is very influenced by the type of aggregate. There is so much different in strength between RCA and NA. The compressive strength of the recycled aggregate concrete is weaker than normal concrete. From the result obtain, the average of 1:3 cement to aggregate ratio of NA is 23.317N/mm^2 for RCA is 7.216 N/mm^2. There is a huge different between RCA and NA concrete compressive strength [6].

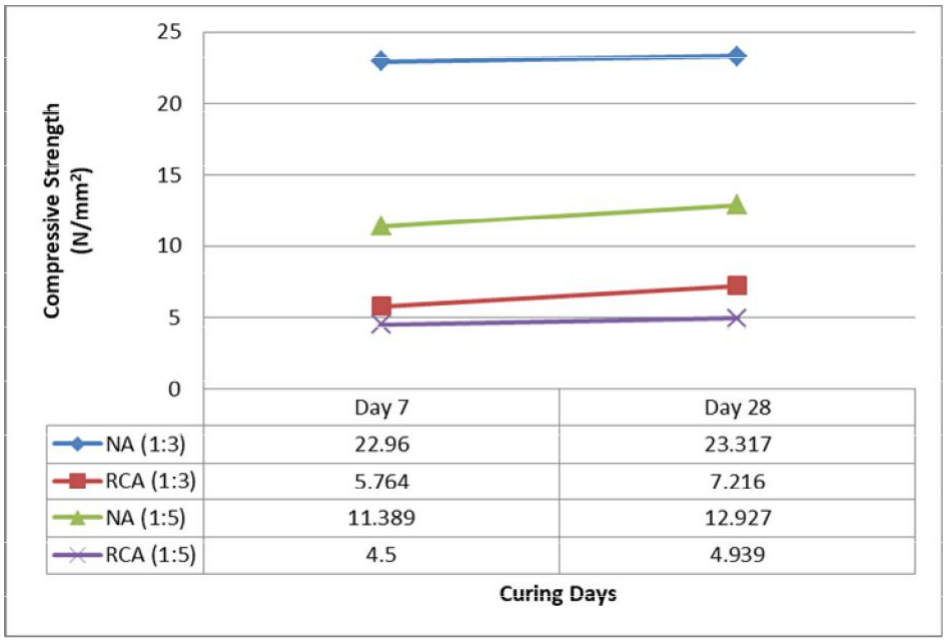


Figure 4. Compressive Strength of Pervious Concrete Using Different Cement Aggregate Ratio

4.2.. Infiltration Rate

The actual outcome of infiltration rate result for the RCA and NA pervious concrete with different cement aggregate ratio is referring to Table 2.

Table 2. Pervious Concrete Infiltration Rate Data for Both RCA and NA

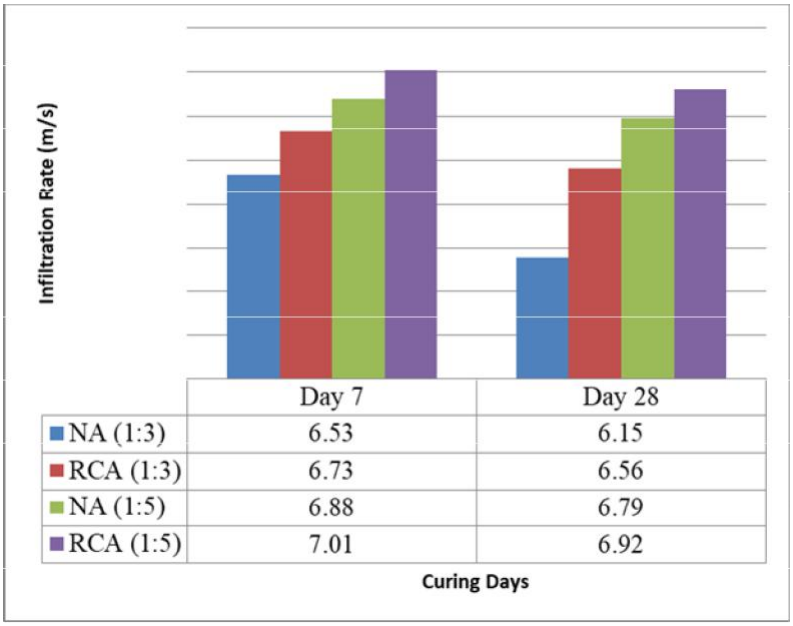
Water Cement Ratio	Agg. Size (mm)	Type Of Agg.	Cement agg. ratio	Curing (Day)	Infiltration Rate (mm/s)
0.3:1	5-10	Natural aggregate (NA)	1 : 3	7	6.53
				28	6.15
			1 : 5	7	6.88
				28	6.79
		Recycled concrete aggregate (RCA)	1 : 3	7	6.73
				28	6.56
			1 : 5	7	7.01
				28	6.92

Figure 5 shows the graph of infiltration rate of RCA pervious concrete and NA pervious concrete with given cement aggregate ratio mix proportions. The infiltration rate of the curing day 28 lowers that curing at day 7 due to the small shrinkage in the pervious concrete. The steady decrease in water penetration coefficient was found after the cement hydration reaction [6].

For NA pervious concrete, the infiltration rate for day 7 was 6.53mm/s and day 28 was 6.15m/s for cement aggregate ratio 1:3. NA pervious concrete, the infiltration rate for day 7 was 6.88mm/s and day 28 was 6.79mm/s of cement aggregate ratio 1:5. For RCA pervious concrete, the infiltration rate for

day 7 was 6.73mm/s and day 28 was 6.56mm/s with cement aggregate ratio 1:3. For RCA pervious concrete, the infiltration rate for day 7 was 7.01mm/s and day 28 was 6.92mm/s for cement aggregate ratio 1:5.

The RCA pervious concrete infiltration rate was higher than NA pervious concrete. This was because the pervious concrete sample using NA are having lower water absorption compare to RCA [9]. That mean, RCA water absorption was higher. The data of infiltration rate show that for reading of RCA was higher than NA uses for the pervious concrete for both cement aggregate ratio 1:3 and 1:5.



	Day 7	Day 28
NA (1:3)	6.53	6.15
RCA (1:3)	6.73	6.56
NA (1:5)	6.88	6.79
RCA (1:5)	7.01	6.92

Figure 5. Infiltration Rate of Pervious Concrete Using Different Cement Aggregate Ratio

5. Conclusions

This study proves that recycled-concrete aggregate (RCA) pervious concrete possesses lower compressive strength in comparison to natural aggregate (NA) pervious concrete. Using the right proportion of the cement-aggregate ratio of pervious concrete is necessary in order to determine the optimum strength of the pervious concrete. The RCA pervious concrete with 1:3 cement-aggregate ratios would likely to have higher compressive strength than the RCA pervious concrete with 1:5 cement-aggregate ratios.

Comparing the compressive strength difference between both NA pervious concrete and RCA pervious concrete, it can be concluded that regardless of any cement-aggregate ratio and curing days, the result still shows a lower compressive strength parameters for RCA pervious concrete in comparison to NA pervious concrete.

The infiltration characteristics of pervious concrete were affected by the curing factor. The infiltration rate during the 7th curing day is slightly higher than the infiltration rate at the 28th curing day. On the other hand, the infiltration rate of the NA pervious concrete is slower than RCA pervious concrete regardless of having cement-aggregate ratio of 1:3 and 1:5 respectively. In this study, the focus is more on the RCA pervious concrete. Hence, RCA pervious concrete with cement aggregate ratio 1:5 was higher infiltration rate than RCA pervious concrete with cement aggregate ratio 1:3.

As for the conclusion, the RCA pervious concrete designed using 1:3 cement-aggregate ratio would be more proportionate if the compressive strength is emphasised for the intended use without neglecting the fact that NA pervious concrete will give a better result whereas for infiltration characteristic, it is preferably designed by using 1:5 cement-aggregate ratio in order to achieve higher infiltration rate.

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