Experimental study on compressive strength and infiltration rate of pervious concrete containing recycled coarse aggregate and seawater

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Abstract. In this study, pervious concrete specimens were created containing 100 percent of Recycled Coarse Aggregate (RCA) as a replacement for Natural Coarse Aggregate (NCA) and seawater as a replacement for Fresh Water (FW). Eighteen specimen tests in total were prepared which consisted of nine specimens containing Recycled Coarse Aggregate Seawater (RCAS) concrete and nine specimens containing Recycled Coarse Aggregate Fresh-water (RCAF) as control concrete. Both water to cement ratio of 0.45 and RCA to cement ratio of 0.25 is determined and the mix design is calculated. Fresh concrete was cast on the cylindrical mold of 150 x 300mm in a porous formation. Then the compressive strength and infiltration rate tests were conducted to understand the performance of RCA mixed seawater (SW) at curing times of 3, 7, and 28 days. The results show that the compressive strength of RCAS can reach a peak of around 8.98 MPa compared with RCAF just around 7.27 MPa in maximum curing of 28 days and the value of RCAS samples shows that the infiltration rate is increasing linearly as compressive strength is from three days to 28 days.

1 Introduction

Climate change is a main factor affecting the environmental condition of the earth today which is caused by deforestation [1]. Deforestation has been increasing the high flood risk and more intense rainfall that results in much damage to structural infrastructures such as pavement roads, buildings, etc. Moreover, the rainfall intensity in Indonesia was noted to receive an average of up to 100 mm per day evenly spreading across the nation by *Badan Meteorologi Klimatologi dan Geofisika* (BMKG). The direct material interface between concrete and rainwater in the long term will lead to the degrading of its strength and durability. Therefore, there shall be needed an effective way by means of not only creating durable concrete material but also reducing environmental issues sustainably.

Pervious or porous concrete has become well-known for decades as it has the capability to catch on the run water surface which lets it pass through the ground. It has been designed for being used as parking lots, walking and biking trails, driveways, streets, and other low traffic volumes [2–5] where the infiltration performance in pervious concrete has gained a significant role in which is designed to drain water to the drainage system [2].

The ability to flow water through the ground quickly, reduce pollution, sound absorption, and minimize overheating are some advantages of pervious concrete compared to normal concrete. Moreover, with the porosity, pervious concrete is easy to recharge the soil with water rapidly. Therefore, it is one of the best practices due to its various environmental merits and emerging technology for sustainable facilities and infrastructures [6].

Pervious Concrete (PC) is a mixture that is consisted of cement, water, and a single size of coarse aggregate with or without fine sand. Approximately seven percent of fine aggregate can be added to the pervious concrete mixture to provide additional compressive strength and durability, but it could decrease its infiltration rate and permeability. Moreover, pore size, tortuosity, connectivity, and pore distribution have a significant impact on the durability, and strength permeability of concrete, but porosity is still the main control of these characteristics [7].

Generally speaking, the porosity of this type of concrete has in the range of 15-25% and has around 2 - 6mm per second of the permeability coefficient [8]. In order to generate the porosity of concrete, the coarse aggregate was used with uniform-sized. The size of natural coarse aggregate mixed in pervious concrete is having a range of 10 - 20mm with no fines that affect the strength and the density of concrete due to many pores created. Therefore, the water-cement ratio is considered one of the main factors affecting the concrete workability and porosity which may also increase the strength because it occupies the void between coarse aggregates [9-10].

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In addition, cement paste as a function of bonding in pervious concrete mixture has a significant role in improving compressive strength. The research conducted by Fu et al. [11] showed that the decrease in permeability coefficient and porosity happened due to the additional binder and increasing aggregate size. It is also said that the use of waste aggregate such as plastic and rubber as a natural coarse aggregate can increase permeability values up to 25% replacement [12].

On the other hand, one of the biggest cases that the earth has been facing is mainly construction waste and industrial footprint. Concrete waste as a result of the Construction and Demolition (C&D) of structural concrete is continuously generated around the world. It shows that the increasing number of concrete construction waste every year can reach up to approximately 48% in Korea [13], 850 million tons in the EU, and 123 million tons in the USA [14]. However, most of the waste ended up in landfills as a disposal that produced several deposits. Consequently, it becomes a huge problem for humans' environmental pollution. A possible answer to this case is to recycled the concrete waste and generate an alternative aggregate used in making new concrete that is commonly called Recycled Aggregate Concrete (RAC).

RAC is generally produced in two stages: the first stage is the crushing of demolished concrete and the second stage is the screening and removal of contaminants such as reinforcement, plastics, wood, paper, and gypsum. The crushing process is a main part of producing recycled aggregates which mainly creates Recycled Coarse Aggregate (RCA). Compared with Natural Coarse Aggregate (NCA), RCA has a remains amount of adhered mortar and cement paste to its surfaces that are able to reduce the bonding between old mortar and new one. Further, due to the attached old mortar, RCA has a higher level of water absorption than NCA and therefore using RCA in concrete mixing is significant for engineers or practitioners to understand this carefully. One method that can be possible to get rid of high water absorption is to add a certain amount of water to saturate RCA during the mixing process.

In terms of the compressive strength of RAC, research work has been done intensively. There seems to be common that the lowest replacement ratio (RCA to NCA) is up to 30% not affecting the compressive strength [15]. However, when the replacement ratio is accounted for 50% or more of the total, the compressive strength is still reached [16-17]. This is because the partial replacement of NCA with RCA does not influence all concrete in the same way. Moreover, Al Ajmani et al. [18] used a replacement level of up to 80% recycled aggregate with water to cement ratio (w/c) of 0.31 and the results showed that the compressive strength was able to reach 60 MPa at 28 days and 77 MPa at 56 days. Yehia et al. prepared several concrete samples with 100% recycled aggregate and found that the compressive strength and durability were acceptable [19]. Moreover, many researchers stated that RAC is capable and durable concrete as an alternative to Natural Aggregate Concrete (NAC). It is also shown that the strength properties of RAC such as compressive strength are indistinguishable from NAC with its high limiting value [15, 20–21].

The use of RCA in making pervious concrete may differ from other concrete technology. So far, there is less information about the strength and infiltration rate of pervious concrete by using a single size of RCA and different time curing. Zang et al. [22] were solely performing physical and mechanical strength experimentally in the laboratory with RCA size of 5-10 mm. They also prepared additional material mixtures such as cement, silica fume, superplasticizer, and fresh water. The result showed that the compressive strength decreased when the ratio of water-cement was 0.275. Moreover, sriravindrarajah et al. [23] in their mix design of pervious recycle aggregate concrete stated that using aggregate size variation from 5 to 13 mm and 13 to 20 mm increased the compressive strength gradually at 28 days.

Another problem is water in mixing concrete production. Sometimes the water has limited access to find and resources to obtain. And we know that three-fourths is coved by seawater and few are fresh water. Accordingly, researchers have utilized seawater not only for mixing fresh concrete but also for curing periods. Abdel-Magid et al. [24] revealed that the increase in compressive strength was reachable when mixed with fresh water and cured with seawater at 7 and 90 days, but there is no vital change happened at 28 days. Further, the early-age compressive strength was obtained when using seawater as mixing and curing from 4 to 10% at 7 days.

Therefore, the aim of this study was focused on utilizing 100% RCA as NCA replacement and seawater as mixing in producing pervious concrete. Portland Composite Cement (PCC) was used as cementitious material with a w/c of 0.45. The cylindrical samples were formed and there were cured in fresh water with different curing times of 3, 7, and 28 days. Properties of compressive strength and infiltration rate were then investigated to understand the behavior of recycled pervious concrete.

2 Materials and methods

2.1 Materials

The physical and mechanical properties of the selected Portland Composite Cement (PCC) can be seen in Table 1. This PCC is also soundness qualified.

Table 1. Physical and mechanical properties of cement.

Density	Setting Time (minutes)		Compresive Strength (MPa)		
	Initial	Final	3 d	7 d	28 d
3.15	90	135	13.24	21.57	25.49

There are two aggregates with a single-size of 19 mm. The first is recycled coarse aggregate obtained from crushed waste of structural concrete. The second is natural coarse aggregate as the control aggregate in making pervious concrete.

Table **2** shows the physical and mechanical properties of both aggregates.

Seawater is used for mixing to foam cement paste as a binder of pervious concrete with a salinity of 3.5%.

Concrete mix design was calculated based on Saturated Surface Drying (SSD).

Table 2. Physical and mechanical properties of aggregates.

Type	Aggregate Size (mm)	Apparent Density (kg/m^3)	Bulk Density (kg/m^3)	SSD (kg/m^3)	Water Absorbtion (%)	Chrushing Value Index (%)
RCA	19	2697	2523	2588	3.54	29.24
NCA	19	2551	5212	2473	2.54	25.42

2.2 Mix design and preparation of specimens

Mix design was done carefully to meet the pervious concrete design. Binder-aggregate ratio (b/a) has been specified at 0.25 with no fines and the water-cement ratio (w/c) has also been decided to 0.45.

Table **3** shows the detailed program experiment for both sample's concretes. RCA has relatively high water absorption compared to NCA because of the attached old mortar and cement paste on its surfaces. To prepare concrete specimen, a cylindrical mold was used with a dimension of 150 x 300mm. A total of eighteen specimen tests were prepared consisting of two groups where the first group was nine specimens containing Recycled Coarse Aggregate Sea-water (RCAS) concrete and the other was nine specimens containing Recycled Coarse Aggregate Fresh-water (RCAF) concrete as control concrete.

Table 3. Detailed program of the experiment.

Type	Material Composition	b/a	w/c	The Number Specimens Test	Curing Period (days)
RCAF	PCC	0.25	0.45	3	3
	Fresh Water			3	7
	RCA			3	28
RCAS	PCC	0.25	0.45	3	3
	Sea Water			3	7
	RCA			3	28

The mixed proportion of each group of sample types can be seen in Table 4. The mixing processes were firstly poured the 100% RCA into concrete mixtures with a capacity of 100 kg. Cement and water were then placed after 20 seconds of first mixing. Finally, 120 seconds later, the specimens were ready to be foamed into cylindrical molds [22]. Fig. 1 shows the results of fresh and hard pervious recycled concrete during production.

Table 4. Mixing proportion of both sample concretes.

Type	Cement (kg)	RCA (kg)	Water (kg)
RCAF & RCAS	8.726	1.506	0.592

Fig. 1. (a) fresh and (b) hard concretes.

2.3 Curing period

All specimens were demoulded after 24 hours from the beginning of their mixtures. Then, they were cured in fresh water for 3, 7, and 28 days. Before compressive strength and infiltration rate tests were done, the specimens were moved out from the soaking tube for 24 hours. This is intended to make sure that the specimens are dry enough for testing.

2.4 Testing samples

Each sample of RCAS and RCAF was measured and analyzed by using modified infiltration devices and a Compressive Testing Machine (CTM) to obtain the infiltration rate and compressive strength values for both two types of concrete samples for 3, 7, and 28 days of curing. Here, before conducting the compression testing, we first analyzed the samples by using modified ASTM C1701 as shown in Fig. 2 and then the samples were tested under compressive load as seen in Fig. 3.

Fig. 2. Infiltration test.

Fig. 3. Compression test.

The infiltration rate measurement shows the sample of pervious concrete which was wrapped together with a PVC ring. All the surfaces of both were sealed with tape wrap to ensure that the water was not flowing out the sides and any holes during the testing. Further, one litter of fresh water was poured into a PVC ring through the cylindrical sample and the time was counted from starting when freshwater reached the surface of the samples until there was no presence of fresh water. Based on the result, the infiltration rate was then computed as the volume flow rate divided by the cross-sectional area [2].

CTM has been widely used as a main tool to determine the compressive strength of concrete. In this research, we conducted the compressive strength test from three cylindrical samples at each curing time of 3, 7, and 28 days. Then the values were calculated as the maximum load divided by the total sectional cross-sectional area of the sample. The average values are presented in this paper.

3 Results and discussions

3.1 Compressive strength

Fig. 4 shows the compressive strength results from the average measurement of three cylindrical specimens at different testing times of 3, 7, and 28 days. It is recognized very well that the compressive strength of pervious concrete with 100% recycled coarse aggregate slightly increased while testing time also increased. At three days of testing of RCAF, the highest compressive strength was achieved at about 6.25 MPa, while the RCAS was around 7.50 MPa. It is noted that seawater will increase the early compresive strength of concrete. After seven days of curing, the highest compressive strength was achieved around 7.27 MPa by the RCAF group and 4.88 MPa by the RCAS group. However, the highest compressive strength value for both RCAF and RCAS at 28 days was gained at 7.27 MPa and 8.98 MPa respectively.

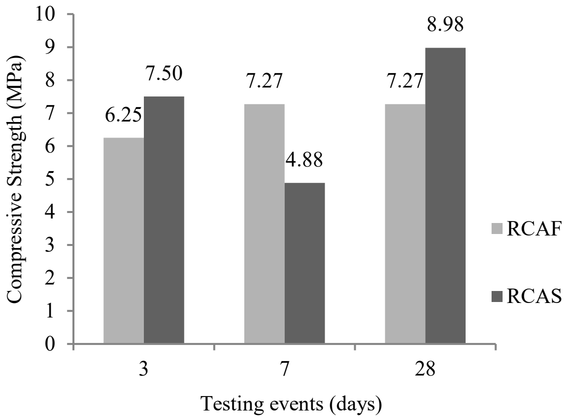

Fig. 4. Compressive strength test results

From these results, however, with RCAS, the trend of compressive strength test gradually increased from three days to seven days compared with RCAS. The compressive strength of RCAS is slightly unpredictable. From three to seven days it fell sharply to 34.93% and then increased significantly to 45.65% at 28 days of curing time. These may be caused by the effect of salt crystallization formation from seawater mixture filling the porosity of RCA during the hardening of samples [25].

Furthermore, the correlation between the weight of pervious concrete and time measurement can be seen in Fig. 5. It shows that the weight of pervious recycled coarse aggregate concrete mixed with seawater is noticeably higher than that of mixed freshwater at all-day curing. At three days, both the weight of RCAF and RCAS was 9.81 kg and 12.48 kg respectively. On the other hand, the specimens of RCAF and RCAS were measured at seven days, the weights for both reached around 10.03 kg and 12.80 kg respectively. Moreover, weighing of RCAS specimen was able to achieve about 12.57 kg and RCAF was about 10.17 kg. In this work, therefore, salt crystallization has significant role for increasing the weight of samples because the voids of pervious concrete are filled with salt criystals.

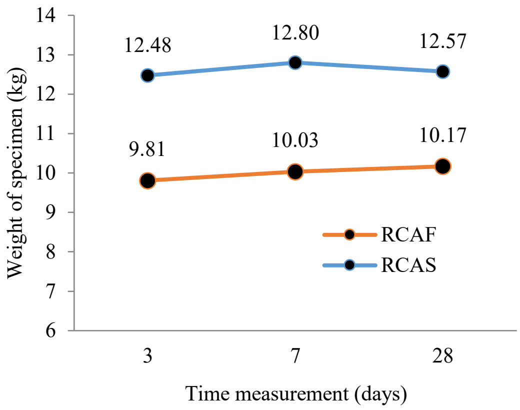

Fig. 5. Weight of specimen samples.

3.2 Infiltration rate results

Other significant property of pervious concrete is infiltration rate performance which was under unsaturated condition. Fig. 6 shows that the results of infiltration rate value of RCAS has reached nearly 20.24 mm/s, while that of RCAF was only able to achieve about 17.93 mm/s at 28 days of measurement. While infiltration rate tests of RCAS at three and seven days were about 15.69 and 18.57 mm/s and RCAF was nearly 17.95 and 18.57 mm/s respectively. Unsaturated infiltration respected to time age of measurements shows that the increasing time curing has a high correlation to infiltration rate for RCAS, but the remaining state is that of RCAF.

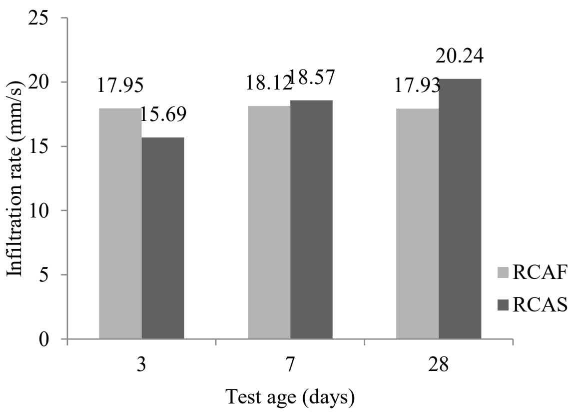

Fig. 6. Infiltration rate results.

Fig. 7 reveals that the compressive strength of RCAF does not tend to be affected by infiltration rate very much. When the compressive strength value was an upward trend to 14% from 3 days to 7 days, the infiltration rate accounted for just 0.9%. While the compressive strength value from 7 days to 28 days was static, the infiltration rate did not steeply decrease for only 1%. Even though there is a little increase in the compressive strength of pervious concrete RCAS, it does not mean that the increase in infiltration rate does. This is because of formation of voids in every sample mixture is probably different.

However, in comparison to Fig. 8, it can be seen obviously that the trend of compressive strength of pervious concrete RCAS tends to be affected by infiltration rate. At first, the compressive strength dropped dramatically around 34.85% from 3 days to 7 days, but the infiltration rate increased significantly to 18.35%. Further, testing at 28 days from 7 days, the compressive strength almost reached doubled to a high of 83.73%. Similarly, the infiltration rate was steep rise to a percentage of 8.99. From the description, it seems that the increased values of compressive strength might rise the values of the infiltration rate certainly.

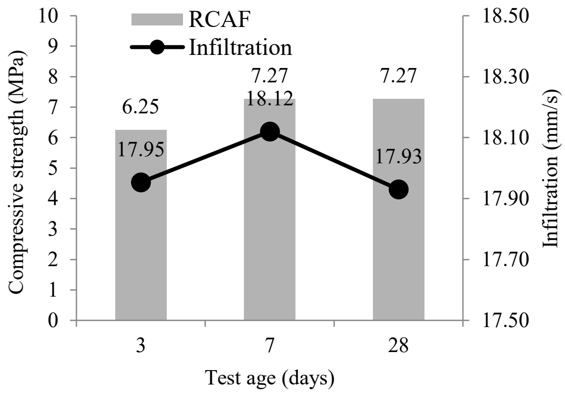

Fig. 7. Correlation between compressive strength, infiltration rate, and age test of RCAF.

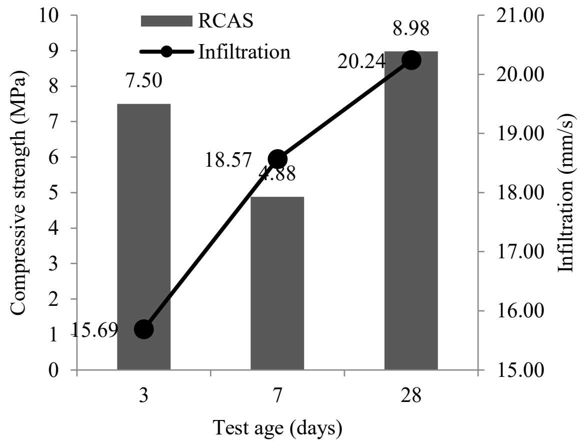

Fig. 8. Correlation between compressive strength, infiltration rate, and age test of RCAS.

4 Conclusions

From the experimental study of pervious concrete containing recycled coarse aggregate and seawater mixtures, we might conclude that utilizing recycled course aggregate from waste concrete as replacement of natural course aggregate and seawater as replacement of freshwater has a pivotal important for sustainable material construction in making pervious concrete. It can be seen that the compressive strength of RCAS can reach to peak around 8.98 MPa compared with RCAF just for around 7.27 MPa in maximum curing of 28 days. This is due to the additional seawater as the mixture has increased the weight of RCAS samples because of the salt crystallization filled in voids of concrete as a consequence the compressive strength is improved. Moreover, the value of RCAS samples shows that the infiltration rate is increasing linearly as compressive strength is from three days to 28 days.

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