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EXPERIMENTAL STUDY ON THE PERFORMANCE OF PERVIOUS CONCRETE MADE WITH VARIOUS COMPOSITIONS OF RECYCLED CONCRETE AGGREGATE

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Abstract

The utilization of recycled aggregates in concrete mixtures is one of the efforts to reduce concrete waste generated by the construction sector or generated by concrete testing laboratories. This research was carried out to obtain the characteristics of concrete using recycled aggregate materials to be utilized in the manufacture of pervious concrete. Pervious concrete is a sustainable material for pavement that contributes to rainwater management and the expansion of water infiltration areas, considering that the location of this study is situated in the northern part of Bandung, which is an area with the potential for rainwater infiltration. The method used in this research is laboratory testing including testing recycled aggregate materials and cement, making job mix formulas, making concrete cylindrical specimens, and testing concrete consisting of compressive strength, and permeability test. The tests were conducted at 7, 14, and 28 days of concrete age. The results of this study obtained the most optimal use of recycled aggregate material at 50 percent. The strength of the concrete produced at the age of 28 days at optimum conditions is for a compressive strength of 4.5 MPa, and permeability of 3.09 cm/s.

Keywords: Concrete, Pervious concrete, Recycled aggregate.

1. Introduction

Pervious concrete has gained popularity as a sustainable and environmentally friendly paving material due to its ability to allow water to pass through, reducing stormwater runoff and minimizing the risk of flooding [1-3]. One way to further improve the sustainability of pervious concrete is to make it from recycled aggregates from concrete test specimens [4]. Recycled aggregate may be used for natural aggregate to minimize costs [5]. Numerous governments worldwide have implemented controls to reduce the use of fresh aggregates and to increase the recycling of waste concrete for material reuse where environmentally, technically, and financially feasible [6].

Recycled concrete aggregate (RCA) can reduce waste and the need for virgin aggregate in concrete mix designs. These are two significant environmental considerations that need to be taken into consideration in the context of sustainable and responsible management [7]. One of the key advantages of using recycled aggregates in pervious concrete is the potential increase in water permeability. Pervious concrete's water permeability tends to increase with the percentage of recycled material added, making it a more practical stormwater management option. This is probably because water can pass through the concrete at comparatively high rates because of the linked void spaces that occur in the material [8].

However, there may be issues with the compressive strength of pervious concrete made with recycled aggregate. Research has indicated that the link between 28-day compressive strength and porosity may be negatively impacted when recycled concrete aggregate is used in place of natural aggregate [9]. The porosity of pervious concrete ranges from 15 to 35% by volume, the usual water permeability ranges from 2 to 12 mm/s, and the compressive strength ranges from 5 to 25 MPa. Cement-based pervious concrete has an aggregate-to-binder ratio of 4 to 6 by mass. According to several studies, increasing the aggregate-to-binder ratio reduces compressive strength and elastic modulus significantly [10, 11]. Nevertheless, factors such as binder materials, aggregate size, and specimen shape can have a marginal effect on this relationship [9, 12].

Pervious concrete employs the same materials as conventional concrete. Pervious concrete is created by eliminating fine aggregate and using coarse aggregate with a narrow or uniform grading, which allows for relatively low particle packing. This creates porosity in the concrete, which is well-suited for its intended application and rainfall intensity. The porosity and interconnectivity of pores are important characteristics of pervious concrete [10]. The extent of compactness was one of the crucial parameters affecting the pervious concrete's strength and hydraulic characteristics; a higher degree of compaction resulted in the maximum strength and lowest hydraulic conductivity. According to the test results, cement amount, not the size of the particles employed, determines more of the pervious concrete's fresh and tensile qualities [13].

Concrete from different sources or unidentified sources should only be utilized to produce it if a thorough investigation and appropriate testing show that it will be of sufficient quality for the intended use. This is because it's possible that changes in the source concrete's characteristics could have a negative impact on changes in the RCA concrete's qualities [14]. Recycled concrete aggregate (RCA) is one concrete waste material that may be used in methods to create pervious concrete, which benefits the environment by reducing the quantity of construction waste and natural aggregate consumption. Pervious concrete is a great option that is becoming more and more popular as a tool for sustainable development because of its benefits for the environment. Being composed of little to no fine particles, it is also a particularly unique type of concrete with significant porosity [15].

Regardless of its size, recycled concrete aggregate (RCA) is usually crude and angular due to the crushing of virgin aggregate particles and the cement paste that is still stuck to the aggregate surfaces. To improve workability, it may be necessary to use a combination of RCA and natural aggregates with more rounded shapes. Additionally, the aggregates' grading and proportioning should be carefully considered to ensure a well-graded mix that is both workable and durable. This can result in concrete mixtures that are harsh and difficult to finish [16]. Overall, the effectiveness of recycled aggregate-based pervious concrete made from concrete test specimens is a promising area of research. By carefully considering the mix design and properties of the recycled aggregates, it is possible to create a pervious concrete that maintains adequate compressive strength while leveraging the benefits of improved water permeability and sustainability [17, 18].

In most cases, aggregate from construction waste-old concrete that has been removed and demolished from foundations, pavements, bridges, or buildings—has been employed in prior studies on the use of recycled aggregate. After being crushed, these are divided into different size fractions. Meanwhile, the utilisation of recycled aggregate from waste concrete test specimens left over from testing the compressive strength of concrete in the laboratory is still not widely utilised as a pervious concrete mix material. Therefore. this study will investigate the performance of pervious concrete made from recycled aggregates obtained from concrete test specimens. Our goal is to assess its mechanical properties, including compressive strength, and permeability test to gain valuable insights into the practicality and efficiency of integrating recycled aggregates in pervious concrete. This study could encourage using recycled materials in infrastructure and help develop more environmentally friendly construction methods.

2. Research Methods

2.1. Materials preparation

Pervious concrete is made up of cement, coarse aggregate, and water. The coarse aggregate used in this study was aggregate from crushed concrete waste. The concrete waste used is a former test piece of hard concrete testing produced in the materials and concrete laboratory of the Civil Engineering department, Politeknik Negeri Bandung. Concrete test specimens are piling up next to the laboratory in significant numbers (Fig. 1). Each year, the number of waste concrete test specimens increases by more than 100 specimens. The crushing and sieving of waste concrete specimens was conducted as a basis for the substitution of coarse aggregate for concrete mix design in pervious concrete pavements.

The equipment used for the crushing and sieving of waste test specimens is a stone crusher machine (Fig. 2). The machine can break stones measuring 10 mm to 350 mm in diameter into split rocks measuring 5 mm to 30 mm. Waste concrete test specimens in the form of cubes, cylinders, and blocks are inserted one by one into the stone crusher to be crushed into split rock. The split rock is sieved using a 10 and 20-mm sieve contained in the stone crusher

In the early stages of the research, material testing was carried out to identify the properties of the materials utilized, as well as to obtain the variables required in the calculation of concrete mix design. The material forming pervious concrete consists of PCC cement, coarse aggregate, and water. Cement testing is only carried out on its specific gravity, while other characteristics are not tested because they meet the quality standards in civil engineering construction. Water testing is also not carried out, because the water used is according to drinking water standards. Testing of coarse aggregates includes:

- Specific gravity in accordance with ASTM C.127-93
- Absorption in accordance with ASTM C.129-93
- Solid and loose content weights in accordance with ASTM C.29-95
- Sieve Analysis in accordance with ASTM 136-96a

Fig. 1. The concrete waste.

Fig. 2. Stone crusher machine.

2.2. Concrete mix design

Test specimens were made for testing the compressive strength, and permeability of concrete. The test specimens for compressive strength and permeability testing were 20 concrete cylinders of 150 mm diameter and 300 mm height.

The compressive strength tests consisted of 15 concrete cylinders with details of 3 pieces each for 5 types of recycled aggregate mixes of 0%, 25%, 50%, 75%, and 100%. Permeability test specimens were 1 piece for 5 types of recycled aggregate mixes of 0%, 25%, 50%, 75%, and 100%. The concrete test specimens were tested for compressive strength according to ASTM C.39-96, at the age of 7 days, 14 days, and 28 days. The design of concrete mixtures is carried out according to ACI 52R-10 standard, with a water-cement content of 0.34.

3. Results and Discussion

3.1. Material testing

Recycled coarse aggregates and cement were tested for their physical characteristics as concrete-forming materials. Table 1 shows the results of the coarse aggregate test, and Fig. 3 illustrates the aggregate size distribution of natural and RCA. Based on the findings of coarse aggregate testing, it is possible to deduce that RCA absorbs more water than natural aggregate. This is due to the dry condition of the aggregate, which allows more water to be absorbed. In terms of specific gravity, it is clear that RCA has somewhat lower specific gravity than natural aggregates. For both forms of aggregates, the aggregate grain size distribution yields nearly identical results.

Table 1. The course aggregate test results.

Test Parameter	Test Result	
	Recycled Concrete Aggregate (RCA)	Natural Aggregate
A. Bulk Specific Gravity (SSD)	2.319	2.6
B. Bulk Specific Gravity	2.103	2.53
C. Apparent Specific Gravity	2.683	2.72
D. Absorption	10.36	2.83
E. Bulk Density (gr/cm^3)	1.062	1.44
F. Loose Bulk Density (gr/cm^3)	1.33	1.3

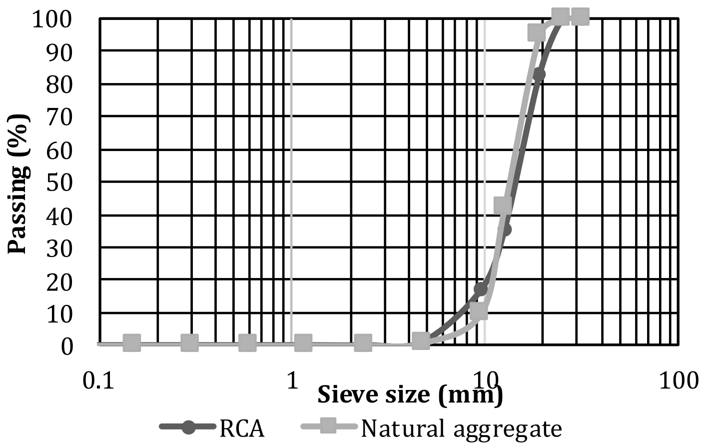

Fig. 3. Aggregate size distribution of recycled and normal aggregates.

3.2. Compressive strength

Compressive strength was evaluated to determine the properties of pervious concrete employing RCA materials as a substitute for natural aggregates. The qualities and amount of recycled aggregate in RCA concrete can affect its compressive strength. The water/cement (w/c) ratio, the proportion of coarse aggregate substituted with RCA, and the amount of adherent mortar on the RCA are all elements that might affect compressive strength in RCA concrete [19]. ASTM C-39 test standards are used to evaluate concrete cylinders with a diameter of 150 mm and a height of 300 mm. Figure 4 depicts the concrete compressive strength testing procedure.

As shown in Fig. 5, Compressive strength at day 28 is 2.78 MPa for natural aggregate mixtures (0% RCA). Compressive strength for the RA mixture on day 28 was 4.02 MPa, 4.52 MPa, 3.89 MPa, and 3.69 MPa for the 25%, 50%, 75%, and 100% RCA mixtures, respectively, and the optimal degree of RCA replacement for pervious concrete is 50%. There was a 23% decrease in compressive strength from the most optimum aggregate mixture in a mixture made up entirely of recycled material. As the proportion of recycled aggregate is raised, test results for compressive strength drop, which weakens the link between cement paste and aggregates. Additionally, producing various Interfacial Transition Zones (I.T.Z.) during the concrete's strength growth phases affects the microstructure-level strength development of the concrete [20].

In accordance with ACI 522R, the compressive strength of natural aggregate pervious concrete, which is suitable for several uses, such as parking spaces, residential streets, pavement-sidewalks, and light traffic pavements, ranges from 2.8 to 28 MPa, with typical values of about 17 MPa. As a result, the results for all RCA replacement levels in this experimental study revealed that the results fall within the predetermined ranges.

Although opinions vary on how much of a reduction there is, concrete using recycled concrete aggregate (RCA) often has a little lower compressive strength than concrete including natural aggregate. According to certain research, there is a 2–10% decrease in compressive strength. Depending on the mixes' water-to-cement ratio, some claim compressive strengths that are comparable to or even higher than these. RCA mixes often have a larger air content, which might lead to lower strength values. Flexural strength can be reduced by up to 8% when recycled coarse aggregate is used with the same water-cement ratio, and the drop can be considerably larger if recycled particles are also utilized, according to reports [16].

Fig. 4. Compressive strength testing.

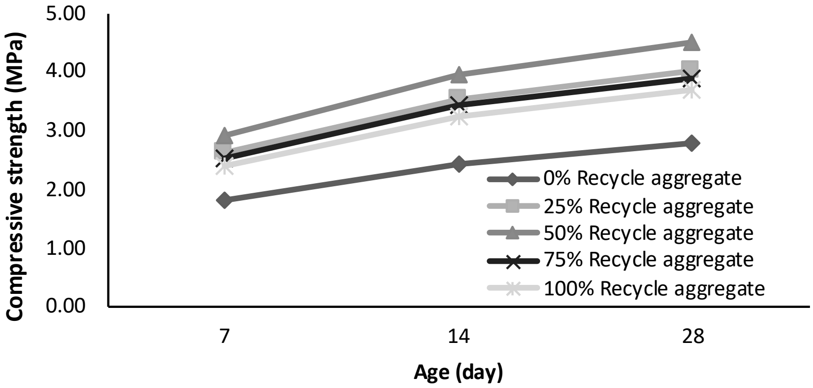

Fig. 5. Compressive strength result.

3.3. Permeability test results

Pervious concrete's permeability is essential for several uses, including parking lots, tennis courts, residential streets, walkways, and light traffic roadways. According to researchers, when compared to regular dense concrete, pervious concrete often has better permeability. Therefore, a permeability test was conducted to estimate its coefficient [12]. The results of the permeability test are shown in Fig. 6. The coefficient of permeability (k) varied from 2.6 to 3.09 cm/s, and the maximum permeability value was observed by 50% replacement of RCA. Water permeability of pervious concrete slightly increased compared to concrete with natural aggregate (zero percent of RCA). According to a previous study, adding recycled aggregates to natural aggregates increased the permeability coefficient, indicating that accomplishing so can improve pervious concrete's capacity to absorb water [17].

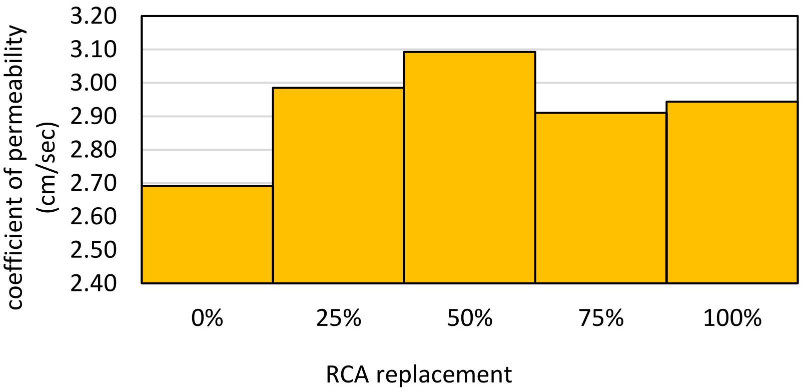

Fig. 6. Permeability test result.

3.4. On-site implementation of pervious concrete

Pervious concrete was utilized as the pavement material for the pedestrian walkway within the civil engineering department area. This walkway is situated in a semi-outdoor environment, where water pooling during rainfall becomes a significant concern. The implementation of porous concrete is anticipated to offer a solution to address the water pooling issue and effectively manage rainwater runoff. Pervious concrete is cast directly on the leveled surface and layered with a combination of recycled concrete fragments and crushed stone. On the pedestrian walkway's sides, soil media is also placed for shrub planting, serving as a part of water infiltration and aesthetic function.

Figure 7 shows the picture of the site implementation of pervious concrete in the pedestrian walkway of the student communal space. The left image shows the area before the implementation of porous concrete; there is a lot of concrete waste scattered around. The right image is the condition after porous concrete has been applied so that it can be used as pedestrian walkways. Figure 8 illustrates the cross section of a pervious concrete pedestrian walkway, which includes several layers to ensure both structural support and effective water management. The layer consists of pervious concrete, soil, sand, and recycled aggregate.

Fig. 7. Before (left) and after (right) on-site implementation.

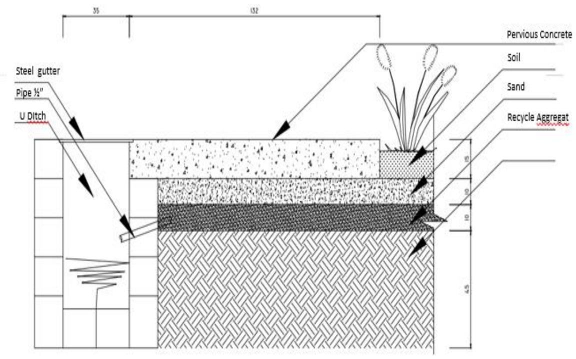

Fig. 8. Cross section of pervious concrete for pedestrian walkways.

4. Conclusions

The effects of recycled concrete aggregate on pervious concrete's characteristics were examined in the study. The percentage of recycled aggregate substituted for natural aggregate in pervious concrete that is constructed using recycled aggregate from used concrete test specimens in the lab determines the compressive strength. With a permeability value of 3.09 cm/s and a compressive strength of 4.5 MPa, the ideal proportion of recycled aggregate use was 50%.

Based on test results, recycled aggregate has good potential to be used as a pervious concrete material for pedestrian, park, or parking areas that do not require high structural strength. By using recycled aggregate, you can at least reduce the waste produced from the rest of the tests in the lab so that it does not pollute the environment.

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