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Compressive Strength, Permeability and Porosity Analysis of Pervious Concrete by Variation of Aggregate and Compacting Method

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Abstract. Pervious concrete is one of the innovation from conventional concrete which has interconnected void, thus enabling it to drain water. Compared to conventional concrete, pervious concrete has different physical and mechanical characteristics, but composed by the same material which is Ordinary Portland Cement (OPC), coarse aggregate, water, fine aggregate, and admixture. The use of fine aggregate in pervious concrete mixture is limited due to the fine aggregate can block the interconnected pores thus lowering the permeable ability of the pervious concrete. The objective of this research is to analyze the characteristics of the pervious concrete which is compressive strength, permeability, and porosity with variation of aggregate and compacting method. The pervious concrete mixture consists of 15%, 20%, and 25% of fine aggregate variations and standard rodding, proctor Hammer, and concrete vibrator as the compacting methods used. The amount of cement used on each mixture is 360 kg/m³, w/c = 0.3, and admixture as much as 2.8% of the cement used. The slump, compressive strength, and porosity test is based on ASTM Standard, while the permeability test is based on ACI Standard. The maximum compressive strength test result is 13.103 N/mm² achieved by the mixture with 25% fine aggregates and compacted using concrete vibrator. The permeability test result ranged from 0.053 cm/s to 1.192 cm/s, and porosity ranged from 2.261% to 41.083%.

1. Introduction

Concrete as a commonly used material on infrastructure needed an improvement to meet the ever-evolving requirements of construction nowadays. As technology continued to develop nowadays, researches about concrete technology began to increase. The development on concrete technology can be seen by the many types of concrete that have its own function, that enables concrete to have high performance and environmentally friendly.

One of the results from the development of concrete technology is pervious concrete. Pervious concrete is one of the innovative from conventional concrete which has interconnected void, thus enabling it to drain water. Pervious concrete has the ability to reduce water runoff from the surface as well as recharging the ground water [1]. One of the efforts to reduce water runoff is the application of pervious concrete. Pervious concrete application has not been well known until 1970s when the water runoff problem hit caused by the rapid development of land, causing frequent flooding. Excessive



water overflow problems cause pervious concrete to be increasingly in demand as a substitute for conventional concrete [2].

Pervious concrete is one of the environmentally friendly construction materials. Pervious concrete can be produced at a relatively lower cost than conventional concrete [3]. The Environmental Protection Agency has established pervious concrete as the Best Management Practice (BPA) for rainwater management. This shows that pervious concrete is worthy of use as one of the most important construction materials in the future, especially in response to green engineering issues. Pervious concrete pavement is rarely used in infrastructure development due to its relatively low compressive strength. In general, pervious concrete has a compressive strength of 2.8 to 28 MPa [4]. The pore size of the pervious concrete is 2 to 8 mm which allows water to flow through the concrete to the lower layer faster than the conventional concrete [5].

Pervious concrete has a larger porosity value than conventional concrete, resulting in lower compression strength. This is caused by the density of the concrete decreases as the porosity increases within the concrete. One way to increase the pervious concrete compressive strength is to use fine aggregate composition in the pervious concrete mixture. The use of fine aggregate compositions may increase the pervious concrete compressive strength, but decrease permeability because the interconnected voids can be covered by fine aggregates [6]. The results in the use of fine aggregate compositions in a pervious concrete mixture should be restricted. The innovation of pervious concrete has several advantages when applied. According to [5], the advantages of pervious concrete applications can reduce areas for water retention, regulate rainwater runoff, reduce slippery roads from water on the road surface, assist aircraft flight with cooling effect, reduce glare on road surface especially when rain, and drain water to the roots of trees even though the pavement is above the ground.

One of the factors affecting pervious concrete characteristics is compaction method [7]. Several compacting methods that can be used in pervious concrete include standard rodding, concrete vibrator and proctor Hammer. These three compacting methods give different effects on pervious concrete characteristics. Based on the description above, this study is intended to determine the effect of aggregate composition and compaction method on compressive strength, permeability, and porosity of pervious concrete.

2. Methodology

The research method used is experimental method. The fine aggregate composition used was 15%, 20%, 25% and the compaction method variation. From these variations, there were nine variations of mixed pervious concrete. Tests performed on fresh concrete in the form of slump testing. Hard concrete test in the form of concrete compressive strength test at age 7 and 28 days, testing of permeability and porosity done at age 28 day.

The stage of determining mix design of pervious concrete composition is by collecting data from various journals and ACI standard 522R-10. The composition of the mixture used in this study is based on the results of trials conducted in the laboratory. The first step in preparing the mix design is to determine the amount of cement used to achieve the compressive strength in accordance with the ACI requirement, which is 360 kg/m^3 . Next determine the value of a/c and w/c according to the results of the trials and the provisions of ACI are $a/c = 4$ and $w/c = 0.3$. Based on the value of w/c , the amount of water required can be determined and with the value of a/c , the amount of aggregates used can be determined. The fine aggregate composition was determined on the basis of the trial results of 15%, 20%, and 25% by weight of the coarse aggregate included in the fine aggregate composition range according to the ACI standard. The additives used are superplasticizer whose amount is determined based on the result of trial in laboratory. The material used in this study consisted of OPC type 1 cement, coarse aggregate sized 9.5-12.5 mm, fine aggregate sized 0.125-4 mm, water, superplasticizer as much as 2.8% to the weight of cement. The composition of the pervious concrete mixture used in this study can be seen in Table 1.

After mixing, fresh concrete test with slump cone based on ASTM standard is used to know the value of the pervious concrete slump. Based on ACI, pervious concrete has a small slump value even 0 due to the small w/c value. After the slump test is done, the placing of the specimen in the 10 x 20 cm cylinder mold can be done. Compaction is done by three methods of compaction that is by using rodding rod, proctor Hammer, and concrete vibrator. Compaction with rodding rod is done by mashing 25 times each layer of samples made in two layers. Compaction with the proctor Hammer is done by pounding the sample 10 times using the proctor Hammer made in two layers. Compaction with concrete vibrator is done by giving vibration for 3-5 seconds in one layer. After all the specimens were compacted, the pervious concrete specimens were allowed to stand for 24 hours in the mold. After 24 hours the formwork is removable and the pervious concrete specimen is cured by using the gunny sack to cover the specimens.

Table 1. Pervious Concrete Mix Design

Fine aggregate (kg/m ³)	Cement (kg/m ³)	Coarse aggregate (kg/m ³)	Water (kg/m ³)	SP (kg/m ³)
216	360	1,224	108	2.8
288	360	1,152	108	2.8
360	360	1,080	108	2.8

The compressive strength test is performed when the test object reaches the age of 7 and 28 days using a compressive strength test apparatus (ASTM). The permeability test is performed by using the falling head permeameter. In this study the tool used has the same tube diameter as the sample which is 10mm. After the test, the difference between the initial and final water levels is measured and then divided by the flow time. Water flow times are calculated from 30 cm to 1 cm. Porosity test was performed using ASTM C192 (2012) standard. Dry the sample using oven at 150°C for 24 hours, then weigh the sample. Soak samples in water for 30 minutes for the sample to be in a state of saturated water, then weigh the sample using the scales in the water. Porosity is the result of comparison of pore volume with total sample volume.

3. Result and Discussion

3.1. Slump Test

The result of the slump test on the pervious concrete mixture with the aggregate variation and the compacting method in this study shows that there is no decrease in fresh concrete or has a slump value of 0 cm. Aggregate variation does not affect slump value in concrete. The use of w/c of 0.30 and super plasticizer of 2.8% of the weight of the cement did not cause the decline of fresh concrete.

3.2. Unit Weight

Unit weight test is performed at 7 and 28 days. Unit weight test is done by weighing the sample. This test was performed with 4 variations of sand quantity with 5 specimens of each variation. The highest pervious concrete unit weight test results were found in the mixture with 25% of the amount of sand and compacted by the vibrator method with the value of 2,375 kg/m³ at 7 days and 2,406 kg/m³ at 28 days. The lowest pervious concrete unit weight test result was found in mixture with variation of 0% sand and compacted by rodding rod method, that is 1,879 kg/m³ at 7 days and 1,885 kg/m³ at 28 days. The results obtained show the increase in unit weight along with the increase in the percentage of the amount of sand in the mixture of pervious concrete. Figure 1 show the results of pervious concrete unit weight test on variations of the amount of sand and compaction methods at the age of 7 days and 28 days. Pervious concrete compacted with the vibrator method produces the largest unit weight among the three compaction methods used. This shows that pervious concrete compacted with vibrator method produces the concrete with the highest density, resulting the greatest value for unit weight among the 3 compaction methods used.

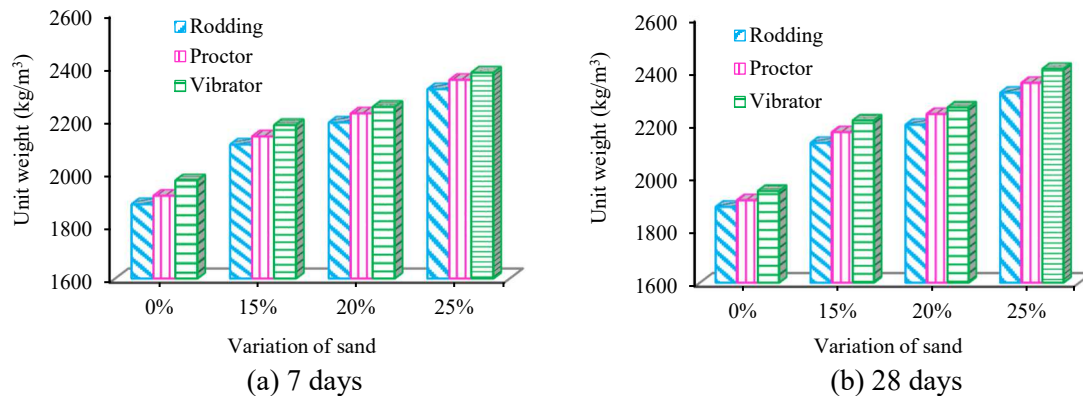


Figure 1. Variations of sand and compaction method on concrete unit weight

3.3. Compressive Strength

The compressive strength test in this study was conducted on 7 and 28 days. The compressive strength test was conducted on pervious concrete with 4 variations of sand quantity and with 5 specimens of each variation. The smallest compressive strength was found on pervious concrete with variation of 0% sand and compacted by rodding method which is 4.592 MPa for 7 days and 4.705 MPa for 28 days. The largest compressive strength was found on pervious concrete with variation of 25% sand and compacted with vibrator method with value of 10.746 MPa for 7 days and 13.103 MPa for 28 days. This shows that the compressive strength increases with increasing amount of sand used in the pervious concrete mixture. All test results of compressive strength in this study are in accordance with the provisions of ACI 522R-2010 standard which states that the compressive strength of pervious concrete ranges from 2.8-28 MPa.

Figure 2(a) shows the compressive strength of pervious concrete aged 7 days with variation in the amount of sand. Pervious compressive strength values of age 7 days are directly proportional to the amount of sand added in the mixture. The highest compressive strength value was found in the mixture of pervious concrete compacted by the vibrator method. This shows the pervious concrete mixture compacted by the vibrator method produce the concrete with the most density between the 3 compacting methods used. Figure 2(b) shows the results of concrete compressive strength test at 28 days. The value of compressive strength of each pervious concrete variation at age 28 days increased from 7 days concrete age. The compressive strength of the pervious concrete continues to increase as the amount of sand increases. The more the amount of sand used in the pervious concrete mixture, the denser concrete it produces. This is because the sand fills the voids in the pervious concrete so that the concrete gets denser.

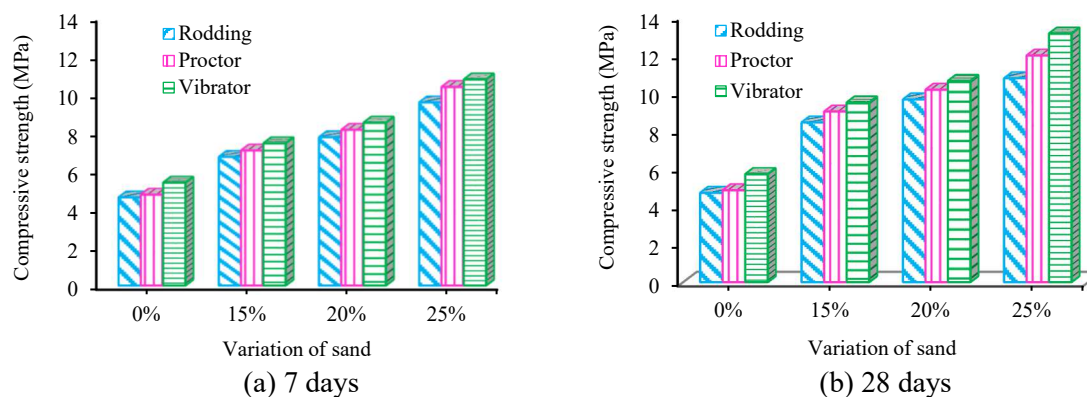


Figure 2. Variations of sand and compaction method on compressive strength

3.4. Permeability

The permeability test is performed by using the falling head permeameter apparatus according to ACI 522R-2010 standard. Pervious concrete permeability test was conducted at 28 days. Based on the provisions of ACI 522R-2010, permeability is related to porosity and the void size in pervious concrete. The permeability coefficient (k) is obtained from the average values obtained from the five specimens tested. The value of k is calculated by using a formula of the Darcy equation with several parameters affecting the value of k. Among the sample area and tube, sample height, water level at the start and at the end, and the time required for the water to flow out. The equations used in the calculation of permeability can be seen in Equation 1.

$$k = \frac{A_1 l}{A_2 l} \log \frac{h_2}{h_1} \quad (1)$$

The results of the permeability test are influenced by the amount of fine aggregate and the compacting method used. Based on the provisions of ACI 522R-10, concrete can be categorized as pervious concrete which is permeable if the permeability value is in the range 0.2-1.2 cm/s. This calculation uses the Darcy equation to get the k value and it can be concluded that the permeability value increases along with the increase in the amount of fine aggregate in the mixture of pervious concrete.

Based on Figure 3(a) the permeability value decreases with increasing amount of sand. The compacting method only effect the permeability value slightly. Comparison between the compaction method, the rodding method produce the highest permeability value among the 3 compacting methods used. The smallest permeability value is found in the mixture of pervious concrete with 25% sand, which is 0.053 cm/s. The highest permeability value is found in the mixture with the amount of sand of 0% or without sand with a value of 1.192 cm/s. Based on the results of permeability obtained, the permeability value decreases as the amount of sand in the mixture of pervious concrete increases. This is caused by the more sand in the mixture, the concrete gets denser which causes the water to flow through the concrete slower. Overall, permeability coefficient values in all variations ranged from 0.053 cm/s to 1.192 cm/s. There is a permeability coefficient value of the specimen not included in the permeability value range by ACI 522R (2010) of 0.14-1.22 cm/s, which is all test specimens using 25% of the amount of sand. Other than that, the permeability value with the variation of compaction methods meets the ACI 522R-2010 range.

3.5. Porosity

Porosity test was conducted to the pervious concrete at 28 days. The highest porosity value is found in the mixture without sand or the amount of sand by 0% by using the rodding compaction method which is 41.083%. While the lowest porosity value is produced by the concrete with 25% amount of sand and compacted with vibrator method that is equal to 2,261%. Figure 3(b) shows the effect of variation of sand quantity to the pervious concrete porosity value. Based on Figure 3(b), it can be seen that the porosity value decreases as the amount of sand increases in the mixture of pervious concrete. This is caused by the more amount of sand added to the pervious concrete mix, the more paste is formed within the structure and the number of coarse aggregates decreases, resulting the paste to cover the coarse aggregate more. The more paste causes the voids within the concrete to be filled, so the concrete becomes denser. The more solid concrete has a smaller porosity value.

In ACI 522R-10, there are two ways to determine the pervious concrete pore value. First, the planning of pore content as a first step to determine the composition of the material through the unit weight value of the mixed material. Second, the pore content obtained is the result of the initial planning of each proportion of mixed material used based on the planned weight of cement. This method produces different pore levels per variation. In this test, a second method was used to obtain pervious concrete pore values in the range of 15% -35%.

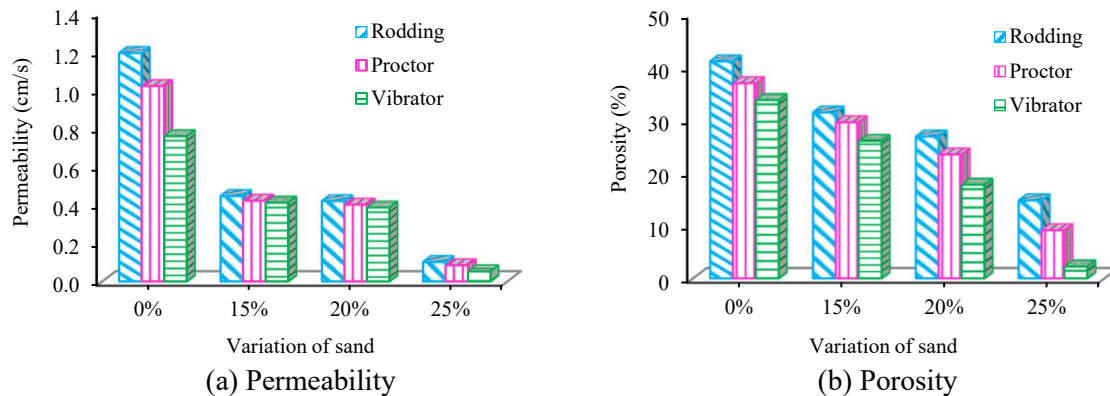


Figure 3. Effect of variations in the amount of sand and compaction method on pervious concrete

4. Conclusion

The compressive strength increases as the amount of fine aggregates increases. The highest percentage change in compressive strength was found in the mixture without fine aggregate which was 46.15% of the mixture with 15% fine aggregate. Permeability decreases as the amount of fine aggregate increases. The highest percentage of permeability changes was found in the mixture without fine aggregate, which is 62.6% of the mixture with 15% fine aggregate. Porosity decreases as the number of fine aggregates increases. The highest porosity percentage change was found in the mixture with 20% fine aggregate which was 87.24% to the mixture with 25% fine aggregate. The highest percentage change in compressive strength was found in the mixture compacted with the standard rodding method which was 10.00% to the mixture compacted by the proctor Hammer method. The highest percentage change in permeability was found in the mixture compacted with the proctor Hammer method which was 25.619% to the mixture compacted by concrete vibrator method. The highest percentage change in porosity was found in the mixture compacted with the standard rodding method which was 10.07% to the mixture compacted with the proctor Hammer method.

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