



# Effect of variation in size of coarse aggregate on compressive strength, porosity, and permeability in pervious concrete

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## Abstract

The Influence of Coarse Aggregate Size Variation on Compressive Strength, Porosity and Permeability of Pervious Concrete. The rapid population growth in Indonesia has led to an increased need for public infrastructure, it causing a reduction in green spaces that serve to absorb water. One solution to mitigate this negative impact is the innovation of pervious concrete, which contains voids that allow water to flow through from the surface into the ground. However, this concrete has low compressive strength but high porosity. The objective of this study is to examine the effect of varying coarse aggregate compositions on compressive strength, porosity, and permeability. In this research, a combination of coarse aggregate was used as the base material in four different mix variations which is 20:40:40, 20:35:45, 20:30:50, and 20:25:55. Total of 36 cylindrical specimens (10 x 20 cm) were required. The target compressive strength ( $F_c'$ ) is 20 MPa, tested at 7 and 28 days. The mix design was calculated following the ACI 522R-10 method, and tests included compressive strength, porosity, and permeability. The test results revealed that the highest average compressive strength at 28 days was achieved in variation 4 (D) with a composition ratio of 20:25:55, achieved a compressive strength of 11,7 MPa, a porosity of 15,28%, and permeability of 0,75 cm/s. These findings confirm that variation 4 (D) meets the minimum criteria for grade D pervious concrete, making it suitable for applications in parkland.

## Keywords

Pervious concrete, Coarse aggregate, Compressive strength, Porosity, Permeability

## Introduction

Along with the increase in population growth, of course, it demands development needs such as residential areas, public land and so on. This change in the composition of land use has an impact on decreasing water absorption capacity, especially in the city of Samarinda, which can be seen from the results of analysts where there is an increase water runoff discharge of 23.81% in the range of 2000 to 2016. To overcome this, the use

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of porous concrete can be applied because it has an effective cavity to support water infiltration into the soil [1].

Pervious concrete is a specialized type of concrete characterized by a very low slump value, typically close to zero. It is produced using Portland cement, coarse aggregates, water, and, when necessary, chemical admixtures, with little or no fine aggregate included in the mixture. The absence of fine aggregates creates interconnected voids within the concrete matrix, allowing water to infiltrate through the material. However, this porous structure generally results in lower compressive strength compared to conventional concrete. Consequently, pervious concrete is commonly applied in areas subjected to light traffic loads, such as sidewalks, parking areas, residential streets, pedestrian pathways, and other low-volume pavement applications [2].

The compressive strength of pervious concrete is strongly influenced by the size of the coarse aggregate used in the mixture. Generally, the use of smaller uniformly graded aggregates tends to produce higher compressive strength values. This occurs because smaller aggregate particles create a denser internal structure and improve the packing arrangement within the concrete matrix. As a result, mixtures with tighter aggregate gradation typically exhibit greater density and enhanced mechanical performance. In addition to affecting density, aggregate size also influences the thickness of the cement paste coating surrounding the aggregates and the characteristics of the void system. Smaller aggregates tend to form smaller and more uniformly distributed pores, while larger aggregates create larger interconnected voids. The dimensions of these pores, together with the thickness of the cement paste acting as a binder, play a crucial role in determining both the strength and permeability of pervious concrete. Consequently, achieving an appropriate balance between aggregate size, pore structure, and cement paste content is essential to optimize the mechanical properties and water infiltration capacity of pervious concrete [3][4][5][6].

From the results of some of the studies above, the size of the coarse aggregate has a sufficient influence on the air cavity and the bond between the aggregates and also the cement used, therefore in this study we will develop the previous research by using various kinds of coarse aggregate sizes and mixed proportions so that the compressive strength, porosity, and permeability produced are more optimal.

## Method and materials

### *Research methods*

This research employed an experimental approach conducted at the Civil Engineering Materials Laboratory of Samarinda State Polytechnic, East Kalimantan. The experimental program was designed to evaluate the characteristics of pervious concrete under controlled laboratory conditions. The overall research procedure and testing sequence are illustrated in [Figure 1](#). Currently, no specific Indonesian National Standard (SNI) has been established for evaluating the quality of pervious concrete.

Therefore, the assessment of compressive strength in this study adopted an approach based on SNI 03-0691-1996 concerning concrete paving blocks. According to this standard, concrete paving blocks are classified into four categories based on their intended applications and performance requirements. The classification criteria used as a reference in this study are presented in Table 1.

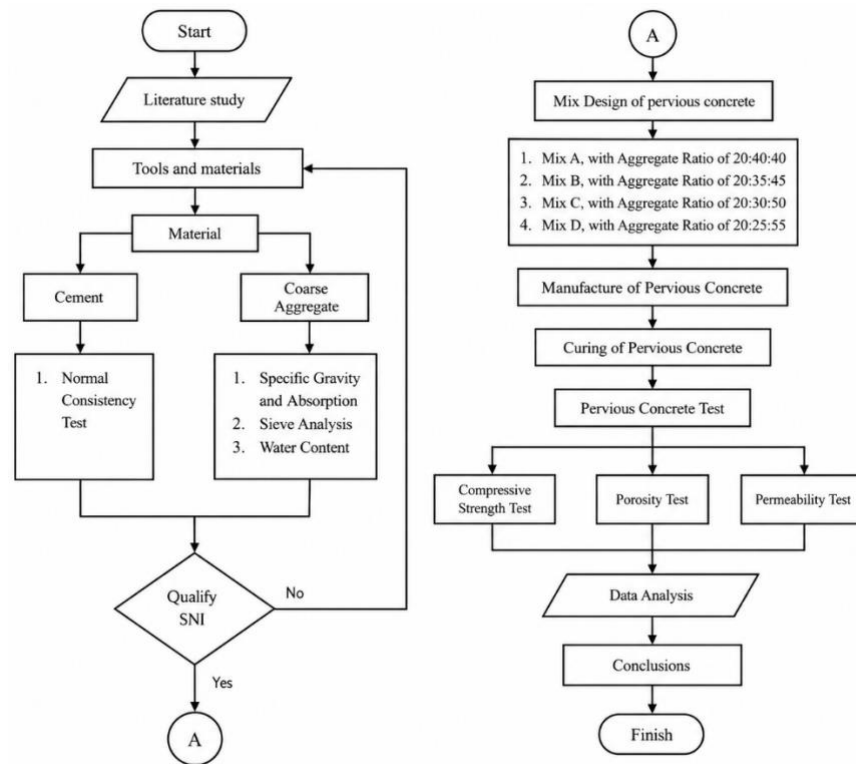


Figure 1. Research Flow Diagram

Table 1. Concrete quality requirements based on minimum compressive strength

Quality	Use	Compressive Strength (Mpa)		Wear Resistance (mm/min)		Average water absorption max. (%)
		Average	Min.	Average	Min.	
A	Road Works	40	35	0,090	0,103	3
B	Parking	20	17	0,130	0,149	6
C	Pedestrian	15	12,5	0,160	0,184	8
D	City Park	10	8,5	0,219	0,251	10

### Materials

The materials used in the manufacture of pervious concrete include:

1. The cement used is PCC (Portland Composite Cement) 3 (three) wheels
2. Hammer coarse aggregate, with 3 size variations:
  - a. Passes 38 mm (1 1/2") sieve and holds 19 mm (3/4") strainer.
  - b. Passes a 19 mm (3/4") sieve and is held on a 9.6 mm (3/8") strainer.
  - c. Passes a 9.6 mm (3/8") strainer and is held on a 4.8 mm strainer (no.4).

3. The water used is PDAM water in the materials laboratory of the Department of Civil Engineering, Samarinda State Polytechnic.

Cement and aggregate testing is also carried out to determine the characteristics and quality of the material, which is needed in the design of the pervious concrete mix design. The results of the cement and aggregate tests can be seen in Tables 2 and 3.

Table 2. Cement Test Results

No	Characteristics	Specifications	Result	Information
1	Normal Consistency	24 - 30%	25%	Qualify
2	Early Binding	45 - 375 minutes	74 minutes	Qualify
3	Specific Gravity	3.00 - 3.20	3.11	Qualify

Table 3. Aggregate Test Results

No.	Characteristics	Specifications	Result	Information
1.	Specific Gravity	2.5 - 2.7	2.64	Qualify
2.	Absorption	Max. 3%	1.60%	Qualify
3.	Sieve Analysis (Modulus of Fineness)	5 - 8	5.48	Qualify
4.	Up Air	Max. 2.5%	0.25%	Qualify
6.	Unit Weight	Min. 1.3 gr/cm <sup>3</sup>	1.42	Qualify
7.	Sludge content	1%	1%	Qualify
8.	Abrasion	Max. 40%	21.80%	Qualify

The results of the cement and aggregate tests above show that the material qualify the Indonesian National Standard for mixed materials pervious concrete.

### Test preparation

The design of the test specimen refers to the mix design of ACI 522R-10, with a compressive strength of 20 MPa and a mixing plan volume of 1m<sup>3</sup>. The test specimen is made using a 10 x 20 cm cylindrical mold with the number of test pieces, the comparison of the mixture proportions, and the material requirements which can be seen in Table 4 -7.

Table 4. Number of Test Object

Test Piece Diameter 10x20 cm	Compressive strength		Porosity and Permeability		Sum (unit)
	Age (Days)		7	28	
	7	28			
A	3	3	-	3	9
B	3	3	-	3	9
C	3	3	-	3	9
D	3	3	-	3	9
Number of Test Pieces					36

After completion of manufacturing pervious concrete Furthermore, the concrete is left for a period of 24 hours, then removed from the mold and covered with a burlap sack that has been moistened with water for approximately 1 day, the treatment process is carried out according to the desired range of days, namely 7 and 28 days. Next pervious concrete dried in the sun to reduce the water contained in the concrete after the

treatment process. The sample is then ready to be tested and then the data is taken and then can draw conclusions.

Table 5. Proportion of aggregate requirement test specimens

Variation	Sum	Volume	Aggregate Comparison (%)	Gross Aggregate Requirements			Total Gross Aggregate Requirement
				2 - 3 cm	1 - 2 cm	0.5 - 1 cm	
				kg/m <sup>3</sup>	kg/m <sup>3</sup>	kg/m <sup>3</sup>	
A	9	0.01413	20:40:40	4.641	9.281	9.281	23.203
B	9	0.01413	20:35:45	4.641	8.121	10.441	23.203
C	9	0.01413	20:30:50	4.641	6.961	11.601	23.203
D	9	0.01413	20:25:55	4.641	5.801	12.761	23.203
<b>Total</b>							<b>92.811</b>

Table 6. Proportion of cement and water

Variation	Sum	Volume	Cement Requirements	Water Needs
A	9	0.01413	6.66	1.800
B	9	0.01413	6.66	1.800
C	9	0.01413	6.66	1.800
D	9	0.01413	6.66	1.800
<b>Total</b>			<b>26.66</b>	<b>7.200</b>

Table 7. Total material requirements

Total material requirements	Unit
Coarse aggregate requirements	92.81 kg/m <sup>3</sup>
Cement needs	26.66 kg/m <sup>3</sup>
Water needs	7.20 kg/m <sup>3</sup>
<b>Total</b>	<b>126.67 kg/m<sup>3</sup></b>

### Sample testing

#### 1. Compressive strength

Compressive strength describes the capacity of concrete to resist compressive forces before cracking or failure occurs. As a key indicator of concrete performance, it reflects the maximum load that a concrete specimen can sustain under compression. Based on ACI 522R-10, the compressive strength of pervious concrete generally varies between 2.8 MPa and 28 MPa. The compressive strength in this study was calculated according to the provisions of SNI 1974:2011 using the following formula:

$$f'_c = \frac{P}{A} \quad (1)$$

With  $f'_c$  is the compressive strength of the concrete (MPa),  $P$  is the maximum load of the tool (N), and  $A$  is the cross-sectional area of the test specimen (mm<sup>2</sup>).

#### 2. Porosity

Porosity is defined as the ratio of the volume of voids to the total volume of a concrete specimen. As one of the key characteristics of pervious concrete, porosity significantly

influences water permeability and strength properties. The porosity value is largely determined by the size and distribution of the air voids within the concrete structure. Based on ACI 522R-10, pervious concrete generally exhibits porosity values ranging from 15% to 35%. The porosity in this study was calculated according to ASTM C642-97 using the following formula:

$$n = \frac{B-A}{B-C} \times 100 \quad (2)$$

Where  $n$  is the porosity of the test piece (%),  $A$  is the weight of the oven dry test piece (gr),  $B$  is the weight of the test piece in the dry saturated condition of the surface (gr), and  $C$  is the weight of the test piece in water (gr).

$$k = 2,303 \frac{aL}{At} \log_{10} \frac{h_1}{h_2} \quad (3)$$

Where,  $k$  denotes the permeability coefficient (cm/s), which describes the ability of pervious concrete to transmit water. The variable  $a$  is the cross-sectional area of the inlet tube or standpipe (cm<sup>2</sup>), whereas  $L$  represents the specimen height (cm). The symbol  $A$  refers to the cross-sectional area of the concrete specimen (cm<sup>2</sup>). The parameter  $t$  is the time interval required for the water level to decline from the initial hydraulic head ( $h_1$ ) to the final hydraulic head ( $h_2$ ), expressed in seconds. Here,  $h_1$  and  $h_2$  correspond to the initial and final water levels within the standpipe, respectively, both measured in centimeters.

### 3. Permeability

Permeability is the ability of rocks to pass liquids through interconnected cavities. Based on ACI 522R-10, the permeability value in porous concrete obtained ranges from 81 – 730 liters/min/m<sup>2</sup> or around 0.14 - 1.22 cm/s. To determine the permeability value in porous concrete, it can be determined by conducting a test using the principle of falling head permeability, which is by measuring the time it takes for water to flow through the sample until the remaining water is in a balanced state equivalent to the water in the sample and the inlet pipe. To calculate the permeability value, the following formula can be used:

$$k = 2,303 \frac{aL}{At} \log_{10} \frac{h_1}{h_2} \quad (3)$$

Where  $k$  is the permeability constant (cm/s),  $a$  is the cross-sectional area of the tensile pipe (inlet pipe) (cm<sup>2</sup>),  $L$  is the length or height of the sample (cm),  $A$  is the cross-sectional area of the sample (cm<sup>2</sup>),  $t$  is the time of receding from  $h_1$  to  $h_2$  (seconds),  $h_1$  is the height of the initial water level of the tube (cm), and  $h_2$  is the height of the final water level of the tube (cm).

## Results and discussion

### *Test results pervious concrete*

The test data were subjected to analysis to assess the influence of mixture variations on the performance of pervious concrete after 28 days of curing. The evaluation focused

on three key parameters, namely compressive strength, porosity, and permeability, which are essential indicators of the mechanical and hydraulic behavior of pervious concrete. The recapitulation of the experimental results for all mixture variations is provided in [Table 8](#).

**Table 8.** Results of the 28-day pervious concrete test recapitulation

No.	Variation	Compressive Strength 28 Days (MPa)	Result				
			Average	Porosity (%)	Average	Permeability (cm/sec)	Average
1.	A	5.9	6.8	17.39%	17.40%	1.04	1.09
		6.6		17.32%		1.25	
		7.8		17.49%		0.99	
		7.5		16.71%		0.92	
2.	B	7.3	8.0	16.28%	16.27%	1.02	1.01
		9.2		15.84%		1.08	
		7.8		15.85%		0.87	
		9.3		15.58%		0.83	
3.	C	9.6	8.9	16.54%	15.99%	0.82	0.84
		11.7		15.56%		0.76	
		12.2		14.84%		0.72	
		11.3		15.44%		0.76	

From [Table 7](#), it is shown that variation A produces the lowest average compressive strength value with a value of 6.8 MPa; Where the permeability and porosity values produced the highest values with an average value of 17.40% and 1.09 cm/second. For the D variation, the highest average compressive strength value was obtained with a value of 11.7 MPa, while for the permeability and porosity values produced the lowest values with an average value of 15.28% and 0.75 cm/sec. The results also show that along with the addition of a smaller aggregate composition in each variation, it will increase compressive strength and decrease the volume of the pores as well as the ability of water to pass through the pores. The test results also showed that the average values of compressive strength, porosity and permeability of 28 days met the ACI 522R-10 specification standard of 2.8 – 28 MPa; 15 – 35 %; and 0.14 – 1.22 cm/second.

### *Relationships analysis of pervious concrete*

The relationship between compressive strength, porosity, and permeability of porous concrete can be used to find out the best variation of the aggregate proportions used. The results of the relationship between the values of compressive strength, porosity, and permeability can be seen in [Figure 2 – 4](#).

Based on the graph above ([Figures 2, 3, and 4](#)), it can be concluded that the compressive strength value of pervious concrete is inversely proportional to the porosity value. From the treatment of mixture variation A to the variation of mixture D, the compressive strength is obtained, the compressive strength is greater but the porosity and permeability are smaller. This shows that the larger the total volume of empty space (pores), the weaker or smaller the compressive strength, and vice versa, and vice versa, if the smaller the total volume of empty space (pores), the higher the compressive

strength. This also shows that the faster pervious concrete can drain water through the pores, the weaker or smaller the compressive strength value, due to a decrease in the bond between aggregates which causes the compressive strength to be weaker. It can be concluded that the porosity value is directly proportional to the permeability value, the greater the porosity value, the greater the permeability value, because the larger the total volume of empty space (pores), the faster the ability of water to pass between the pores, this means that the porosity of a porous concrete has a considerable effect on the permeability produced.

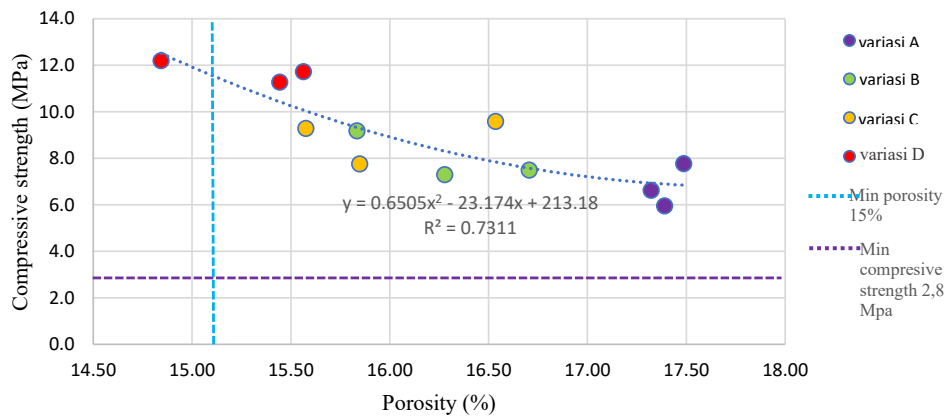


Figure 3. The relationship between compressive strength and permeability

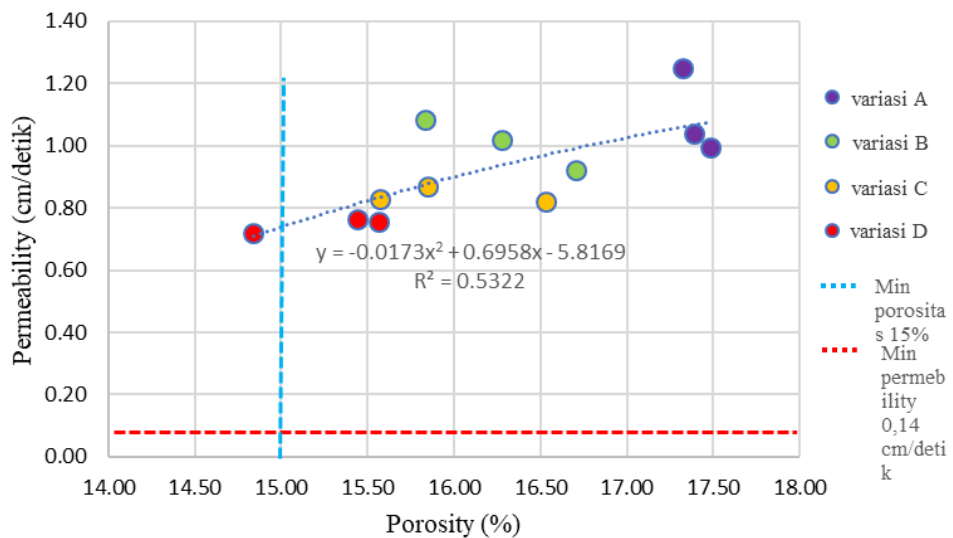


Figure 4. The relationship between porosity and permeability

### Quality group pervious concrete

Based on the results of the calculation of the average compressive strength of all variations of porous concrete and then grouped the quality of porous concrete for each variation based on SNI 03-0961-1996 can be seen in Table 9.

Table 9. Quality group and appropriation of pervious concrete aged 28 days

No	Variation	Compressive Strength (MPa)	End	Use
1.	A	6.8	-	-
2.	B	8.0	-	-
3.	C	8.9	D	Park
4.	D	11.7	D	Park

Based on **Table 9**, the mixture variations A and B produce compressive strength that is not qualified to enter the D grade, while the C and D mixture variations are qualified as D grade concrete, namely with a compressive strength of 8.9 and 11.7 MPa. Based on SNI 03-0961-1996, concrete with D quality can be applied to the garden.

## Conclusion

Based on the results of the test and analysis of pervious concrete with 4 variations of mixtures using 3 types of aggregate sizes, it can be concluded that from the analysis of the test results of pervious concrete samples, all mixtures meet the criteria as porous concrete. Along with the increase in the percentage of use of small coarse aggregates, it will affect the increase in compressive strength, as well as decrease the porosity and pervious concrete perviability values. At the 28-day age variation, the average lowest value of compressive strength was found in variation A of 6.8 MPa and the highest was found in variation D of 11.7 MPa. For the average porosity, the lowest value was found in the D variation of 15.28% and the highest in the A variation of 17.40%. For average permeability, the lowest value is also found in the D variation of 0.75 cm/second and the highest in the A variation of 1.08 cm/second, with compressive strength values of 8.9 and 11.7 MPa; is included in the quality group D with a minimum value of 8.5 MPa which can be applied as a city park.

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