ANALYSIS OF THE EFFECT OF AGGREGATE GRAIN SIZE ON COMPRESSIVE STRENGTH AND PERMEABILITY OF POROUS CONCRETE

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ANALYSIS OF THE EFFECT OF AGGREGATE GRAIN SIZE ON COMPRESSIVE STRENGTH AND PERMEABILITY OF POROUS CONCRETE

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Abstract

This study was conducted to determine the effect of the grain size of Palu's coarse aggregate on the compressive strength and permeability of porous concrete and the highest compressive strength and permeability values obtained in the porous concrete. This study began with testing the coarse aggregate material, then planning and manufacturing specimens with 3 variations in the size of the Palu coarse aggregate, namely 4.75 mm–9.5 mm (BP1), 9.5 mm–19.0 mm (BP2), and 19.0 mm–37.5 mm (BP3) according to the ACI standard 522R-10. The tests carried out were compressive strength testing and permeability testing with a total of 18 specimens at the age of 28 days. Based on the tests carried out, the highest compressive strength of porous concrete is the BP1 variation with a value of 19.77 MPa, while the highest permeability value is the BP3 variation with a value of 840.89 mm/minute. The grain size of the coarse aggregate in Palu is very influential on the compressive strength and permeability of porous concrete. Aggregates with small grain sizes have high compressive strength values but have low permeability values. Meanwhile, porous concrete that uses aggregates with large grain sizes has a low compressive strength value but has a high permeability value. Large porosity due to using aggregates with large grains produces a large permeability value but has a small compressive strength value and vice versa.

Keywords: Porous concrete, Coarse Aggregate, Compressive Strength, Permeability, Porosity

A. INTRODUCTION

Indonesia is a developing country, which is marked by continued infrastructure development. Of all these infrastructures, all of them have the same forming material, namely concrete. Cement, fine aggregate, and additional ingredients are combined to create the composite substance known as concrete (Huang et al., 2020; Zhu et al., 2020; Zhang et al., 2014).

Normal concrete can be said to be a material that is not environmentally friendly, concrete is a material that is difficult to recycle (Ajamu et al., 2012; Li et al., 2021). Concrete also has water and airtight properties, so when concrete is used as the main material for ground cover in Indonesia such as parking lots, roads, parks, or open spaces covered with concrete, it will affect the infiltration of water into the ground. Because the large area covered by this waterproof material makes it a problem for the environment (Lang et al., 2019).

Porous concrete is one of the innovations in the manufacture of concrete which is expected to be more environmentally friendly. Porous concrete is a simple form of normal concrete made by reducing or removing fine aggregate in the concrete mixture.

Based on this background, this study was conducted to determine "The Effect of Variations in Grain Size of Palu Coarse Aggregate on Compressive Strength and Permeability of Porous

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concrete" to obtain maximum compressive strength and permeability values using Palu coarse aggregate.

B. LITERATURE REVIEW

Concrete

Cement, fine aggregate, coarse aggregate, water, and other additives are combined in a certain ratio to form the primary element of concrete, which is a mixture (composite) of several materials (Cosic et al., 2015; Wu et al., 2016). According to Yang et al. (2018), the process of mixing concrete materials is cement paste, namely the hydration process between water and cement, if it is added with fine aggregate it becomes a mortar and if it is added with coarse aggregate it becomes concrete. The addition of materials and other additives will distinguish the type of concrete, for example, steel reinforcement will be added to form reinforced concrete. (Yao, 2018) Concrete has high compressive strength but is weak to tensile strength. Therefore, the use of concrete in building structures is always combined with steel reinforcement so that it can achieve high performance (Yazici & Mardani, 2017).

Fresh Concrete

Good fresh concrete, according to Liu et al. (2018), is fresh concrete that can be mixed, carried, poured, and compacted, and there is no propensity for segregation (separate of gravel from the mortar) or bleeding (separation of water and cement from the mortar). This is due to insufficient segregation and bleeding in the resultant concrete. The properties of fresh concrete include other properties of fresh concrete, namely the ease of workability, the ease of work can be seen from the slump value which is identical to the level of plasticity of the concrete. The more plastic the concrete, the easier it is to work (Aoki et al., 2012).

Hard Concrete

Hardened concrete has an important meaning during its lifetime. The mechanical behavior of hard concrete is the material's capacity to support the structure's load. Compressive strength is a key quality of hardened concrete; when it's strong, the other properties are typically equally good (Barnhouse & Srubar, 2016). Compressive strength of concrete is affected by the quality of its constituent materials, the value of the water-cement factor, and the water-cement ratio, the gradation of the aggregate, the maximum size of the aggregate, the working method (mixing, transportation, compaction, and treatment) and the age of the concrete (Tijani et al., 2019)

Porous Concrete

According to Trisnoyuwono (2014) porous concrete is a simple form of lightweight concrete made by reducing the use of fine grains (sand). Non-sand concrete can be known by various terms such as non-sand concrete, no-fines concrete, permeable concrete, and pervious concrete, the distribution of voids in the mixture evenly and interconnected (the void content ranges from 12% to 25%) causes a decrease in the density of concrete and the effective surface of the granules which must be covered by a cement paste. Generally, the cement requirement per m3

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of concrete ranges from 70 to 130 kg, so it has a direct effect on the portion of cement in the m3.

Application of Porous concrete

According to Trisnoyuwono (2014), Porous concrete has been widely used in several American and European countries. Although this porous or non-sand concrete has a relatively low bearing capacity when compared to normal concrete in general, this porous concrete is very adequate for various applications, including low-volume pavements, residential roads, parking lots, and sidewalks, fields, parks, school yards, and housing.

Porous Concrete Composition Material

Aggregate, The main material used in porous concrete is coarse aggregate. In SNI number 1969:2008, the grain size of coarse aggregate ranges between 4.75 mm (No. 4) to 37.5 mm (No. 112 inch). Coarse aggregate is gravel arising from the natural disintegration of rock or crushed stone produced by the stone crushing industry.

Portland cement, Cement portland is the most commonly utilized building material in concrete construction. Portland cement is defined as a hydraulic cement formed by grinding clinker composed of hydraulic calcium silicate, which typically comprises one or more kinds of calcium sulfate that is ground along with the main ingredient (Cui et al., 2017; Lu et al., 2019).

Water, Water as a cement mixing material acts as an adhesive, so the addition of water in the manufacture of concrete species is a very important element. The role of water as an adhesive occurs through a hydration reaction, where cement and water will form a cement paste and bind aggregate fragments (Debnath & Sarkar, 2020). The water used in the concrete mixture must meet the physical and chemical requirements. This is caused when the setting and hardening processes can run perfectly, resulting in the expected quality of concrete (Fu et al., 2014; Yahia & Kabagire, 2014).

C. METHOD

Mix Design

The method used in this study refers to ACI 522R-10 chapter 6, namely "pervious concrete mixture proportioning". The manufacture and testing of porous concrete were carried out at the Civil Engineering Laboratory, Faculty of Engineering, and Mulawaraman University. The materials used are:

1. Coarse Aggregate, Coarse aggregate used in this research is Palu coarse aggregate. Utilized coarse aggregates pass a 37.5 mm sieve and are retained on a 19.0 mm sieve, pass a 19.0 mm sieve and are retained on a 9.5 mm sieve, and pass a 9.5 mm sieve and are retained on a 4.75 mm sieve. Variations in aggregate particle size are shown in Table 1 below:

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Table 1: Variations in the grain size of the coarse aggregate used

No.	Test Object Sample Label	Variation of Aggregate Grain Size
1.	Beton Porous 1 (BP1)	4.75mm – 9.5mm
2.	Beton Porous 2 (BP2)	9.5 mm – 19.0 mm
3.	Beton Porous 3 (BP3)	19.0 mm – 37.5 mm

2. Portland Cement, Portland cement used in this study is Tonasa Cement with a packaging weight of 50 kg
3. Water, The water used in the manufacture of this porous concretecomes from the Civil Engineering Laboratory, Faculty of Engineering, Mulawarman University, Samarinda.

The equipment used in the form of Physical Test Equipment for fine aggregate and coarse aggregate, concrete mixer for the process of mixing materials, cylindrical mold 15 cm x 30 cm, box mold measuring 40 cm x 40 cm x 10 cm, scales, and molds.

D. RESULTS AND DISCUSSION

Coarse Aggregate Results and Analysis

Coarse aggregate testing in Palu included testing of coarse aggregate analysis, testing of bulk density of coarse aggregate, testing of specific gravity, and absorption of coarse aggregate. The results of these tests are shown in Table 2 below

Table 2: Results of the Palu Coarse Aggregate Test

Test Type	Palu Coarse Aggregate
Filter Analysis	Fine Modulus of Grain = 7.03
Fill Weight	Variation BP1 = 1456.60 kg/m3
	Variation of BP2 = 1573.58 kg/m3
	Variation of BP3 = 1569.81 kg/m3
Specific Gravity	2.80 g/cm^3
SSD Density	2.86 g/cm^3
Apparent Density	2.98 g/cm^3
Absorption	2.15%

Mix Planning

In this study, the mix design used refers to the standard of the American Concrete Institute (ACI) 522R-10 chapter 6. The steps for planning a porous concrete mix are as follows:

1. Determine the Bulk Density of Coarse Aggregate

Based on the content weight test that has been carried out, the value of the weight of each variation is obtained in table 3 below:

Table 3: The value of the weight of each variable used

VariationTest object	Content Weight Value(kg/m3)
BP1	1456.60
BP2	1573.58
BP3	1569.81

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2 . Converting Bulk Weight Value to Fine Aggregate

The weight value obtained is then converted to the coefficient of the use of fine aggregate in the mix design. This study uses 0% fine aggregate in the planning of the mixture, then it is multiplied by a coefficient value of 0.99 and the results are shown in Table 4 below:

Table 4: The results of the content weight value which have been multiplied by the fine aggregate coefficient

VariationTest Object	Converted Bulk Weight Value (kg/m3)
BP1	1442.04
BP2	1557.85
BP3	1554.11

3 . Adding Aggregate Absorption Value to Bulk Weight

The aggregate absorption value is 2.15 percent. Then the bulk weight value obtained after being converted to the fine aggregate coefficient in step 2 above is added to the absorption value. The results can be seen in Table 5 below

Table 5: Results of converted bulk weight values plus aggregate absorption

VariationTest Object	Weight Value Converted+Absorption (kg/m3)
BP1	1473.04
BP2	1591.34
BP3	1587.53

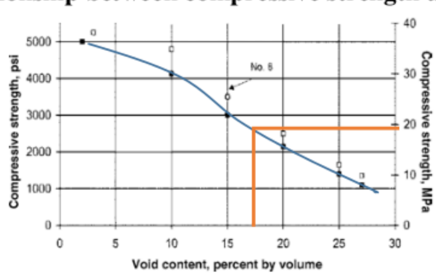
4 . Determining the Cement Water Factor

Based on ACI 522R-10 chapter 6 the water-cement factor value is 0.27-0.34 to the weight of the cement used. In this study, the water-cement factor used was 0.3, which took the middle value of the standard set by ACI.

5 . Determine the Percent Cavity

The void content measured as percent air must be 15% or greater. Determination of the percent void is also closely related to the value of compressive strength. The relationship between the percent of voids and the compressive strength can be seen in Figure 1below:

Figure 1: Relationship between compressive strength and percent void



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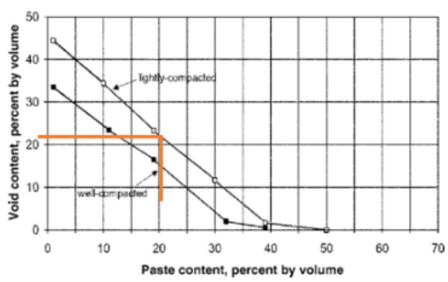
In this study using a compressive strength plan of 19 MPa, then based on the graph in Figure1 the percent void value obtained is 18%.

6. Determining the Paste Volume

The volume of the paste can be determined based on the percent of voids specified in step no. 6. The relationship between the void content and the percent paste volume of mixed can be seen in Figure 2 below:

Figure 2: The relationship between percent cavity and percent volume of pasta



Based on the graph in Figure 2 by connecting the percent cavity value of 18 percent, the result is that the percentage of pasta volume is 25%.

7. Determining Cement Weight

Based on ACI 522R-10 chapter 6 cement weight can be determined by the following calculation

C = [(Vp/(0,315+ w/cm)] x 1000

C = [(0,25/(0,315+ 0,3)] x 1000

C = 406.50 kg/m3

with:

C	=	weight of cement
Vp	=	volume of pasta
w/cm	=	watercement factor

then the weight of cement requirement is 406.50 kg/m3

8. Determining the weight of water

Determining the weight of water using the water-cement factor value that has been determined previously in step 5. Based on ACI 522R-10 chapter 6 the weight of the water can be determined by the following calculation.

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W = cx (w/cm)

W = 406.50 x 0.3

W = 121.95 kg/m3

with:

W = weight of water

C = weight of cement

w/cm = cement water factor

then the weight of the water requirement is 121.95 kg/m3

Compressive Strength Test

The results of the compressive strength test can be seen in Table 6 below:

Table 6: Compressive strength test results of porous concrete

Variation Test Object	Compressive Strength Value(Mpa)
BP1	19.77
BP2	18.97
BP3	15.56

Source: data proceed

Based on these results, the size of the aggregate grain gradation affects the compressive strength of porous concrete. The larger the grain size of the Palu aggregate used, the lower the compressive strength value. Porous concrete that uses aggregates with small grain sizes has a small porosity. Small porosity makes porous concrete denser and the bonds between aggregates become stronger. So that when receiving a compressive force, the porous concrete becomes more stable.

The next factor is the larger the aggregate grains used, the smaller the surface area covered by the cement paste. Porous concrete that uses aggregates with smaller grain sizes allows the cement paste to spread more evenly and covers more of the aggregate in the mix. This increases the bond strength between the aggregates (Kaplan et al., 2021; Wu et al., 2022). Meanwhile, porous concrete that uses larger aggregate grains causes the cement paste to not completely cover the aggregate.

Permeability Test

The results of the permeability test can be seen in Table 7 below

Table 7: Permeability test results of porous concrete

Variation Test Object	Permeability Value(mm/minute)
BP1	340.77
BP2	583.09
BP3	840.89

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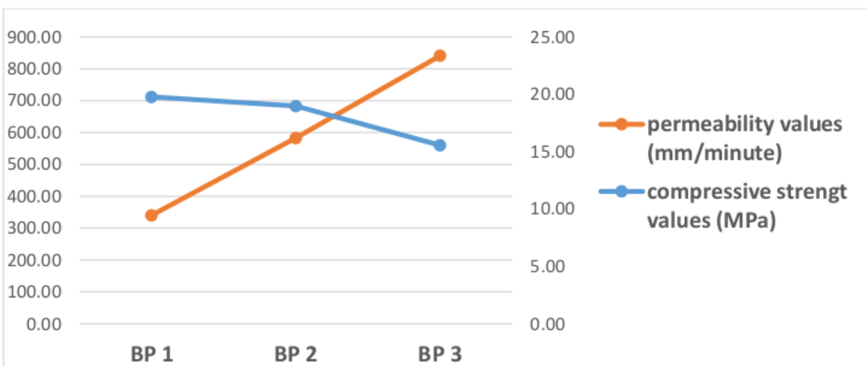
Based on these results, the coarse aggregate grain size of the Palu affects the permeability of the porous concrete. The larger the Palu coarse aggregate grain size, the greater the permeability value obtained. Meanwhile, the smaller the grain size of the Palu used, the smaller the permeability value obtained.

These results can be obtained because porous concrete by using small aggregate grains causes a decrease in porosity. The decrease in porosity is due to the pore cavities filled with these small aggregate grains. The decrease in porosity causes the porous concrete to become denser and more difficult to pass water, so the permeability value obtained is small (Matar & Barhoun, 2022).

Relationship of Compressive Strength with Permeability of Porous Concrete

Based on the compressive strength and permeability tests that have been carried out, it can be obtained a graph that connects the two values. The graph of the relationship between the compressive strength value and the permeability value is shown in Figure 3 below:

Figure 3: Relationship between compressive strength and permeability of porous concrete



According to the graph, compressive strength and permeability are closely related in porous concrete. The greater the compressive strength, the lower the porous concrete's permeability. This also occurs when the permeability value of porous concrete is higher and its compressive strength is lower.

These results can occur because when using aggregates with small grain sizes, the porosity will be reduced because the voids are filled with small aggregates, thus making the porous concrete denser and increasing the compressive strength. In addition, when using larger coarse aggregate, the porosity will increase because the large aggregate grain size creates a large space between the aggregates. The high porosity reduces the compressive strength value because the porous concrete becomes less dense and reduces the adhesion between the aggregates so that the aggregates will rub against each other when receiving compressive forces.

A large porosity value due to using aggregates with large grain sizes results in a large

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permeability value, water will more easily pass through the aggregate gap. Meanwhile, when using coarse aggregate with small grain size, the porosity value will decrease due to the small aggregate filling all parts of the porous concrete. A small porosity value will cause porous concrete to take longer to pass water and be more easily covered by sedimentation.

Potential Uses of Porous Concrete

Porous concrete can be applied as a pavement material in various areas but under certain conditions. Porous concrete has the disadvantage of being sensitive to sub grade conditions with high groundwater levels. Therefore, its use must pay attention to the condition of the existing land to be built. It is necessary to investigate the groundwater level in the area and whether it is possible to build a porous concrete pavement.

Based on several studies that have been carried out related to hydro geological conditions, especially in several areas in East Kalimantan, the application of porous concrete as pavement can be carried out with several conditions that must be met. The first requirement that must be met is that research on the hydrogeology of the soil must first be carried out on the land to which porous concrete will be applied. The second requirement is that the research carried out must be along the area where the porous concrete pavement will be built because based on research the groundwater level can vary even though the distances tend to be not too far away.

E. CONCLUSION

Based on the results and discussions that have been presented, it can be concluded that: 1) Palu coarse aggregate grain size greatly affects porous concrete's compressive strength and permeability. Porous concrete that uses aggregates with small grain sizes has a high compressive strength value but has a low permeability value. Meanwhile, porous concrete that uses aggregates with large grain sizes has a low compressive strength value but has a high permeability value. These results depend on the porosity value, a large porosity value due to using aggregates with large grains produces a large permeability value but has a small compressive strength value and vice versa. The second factor is due to the difference in surface coverage and the space between the aggregates covered by the cement paste. Aggregates with small grain sizes will make the cement paste cover more aggregate grains, and this does not apply to aggregates with larger grain sizes; and 2)The highest compressive strength value of porous concrete is BP1 variation with the aggregate grain size of 4.75 mm – 9.5 mm, which is 19.77 MPa. The second highest compressive strength value is the variation of BP2 with an aggregate grain size of 9.5 mm – 19.0 mm at 18.97 MPa. While the lowest compressive strength value is the variation of BP3 with an aggregate grain size of 19.0 mm – 37.5 mm at 15.56 MPa. The highest permeability value is the variation of BP3 with an aggregate grain size of 19 mm – 37.5 mm at 840.89 mm/minute. The second highest permeability value is the variation of BP2 with an aggregate grain size of 9.5 mm – 19.0 mm at 583.09 mm/minute. The lowest permeability value is in BP1 variation with the aggregate grain size of 4.75 mm – 9.5 mm at 340.77 mm/minute.

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