Mechanical properties of porous concrete and design recommendation for low traffic road pavement in Indonesia

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Abstract. Continued urbanization in the Greater Jakarta area has caused a narrowing of the catchment area due to land use focused on housing and office development. The use of porous concrete as a road pavement can be a remarkable potential to counteract this problem, allowing rainwater to penetrate the concrete, thus reducing runoff and increasing the groundwater level. The study aims to analyse porous concrete's mechanical properties by looking at the influence of porosity level of concrete by 15% and 20% and the impact of maximum size aggregate used by 10 mm and 20 mm. This study's mechanical properties include compressive strength, splitting tensile strength, flexural strength, and shrinkage of porous concrete. The results show that porous concrete with an aggregate size of 10 mm has a splitting tensile strength and flexural strength greater than the 20 mm and a shrinking process faster than the 20 mm. Besides, porous concrete with a porosity level of 15% has compressive strength, splitting tensile strength, flexural strength more significant than 20%, and the shrinkage process faster than 20%. Finally, this study proposed a design recommendation on porous concrete for low traffic pavement. Based on the soil and rain data in Depok City, this study recommends 200 mm thickness of porous concrete layer, 225 mm thickness of subbase layer, HDPE pipe with 100 mm diameter, and 0.38 mm thickness of the impervious liner. Further research on the porous concrete design based on field study is urgently needed to prove the recommended design.

Keyword: Porous Concrete, Design Recommendation, Low Traffic Road Pavement

1. Introduction

Continued urbanization in the Greater Jakarta area has caused a narrowing of the catchment area due to land use focused on housing and office development. Based on BAPPENAS data, in 2010-2035, Jakarta and surrounding areas will have an urbanization rate of 80%. This urbanization rate can cause city compaction, thereby reducing land use as a water catchment area. Based on Depok City's government data, the land area for water catchment areas in Depok City only reaches 19% of the city area. Depok City should have 30% of the land area for water catchments. Therefore, to balance the land requirements, porous concrete implementation as a road pavement could be a solution[1].

Porous concrete is a special concrete that has a high porosity that allows rainwater and water from other sources to penetrate the concrete, reducing runoff and increasing the
groundwater level. The cavity of porous concrete varies from 18% to 35%, with compressive strength from 400 to 4000 psi (28 to 281 kg / cm²). The infiltration ability of porous concrete varies from 80 - 720 liters of water per square meter. Porous concrete generally consists of Portland cement, coarse aggregate, and water. Fine aggregates should not be used or only used in minimal amounts (about <10% of the total aggregate weight). Thus, there is not enough paste to fill the remaining cavities, which cause porous concrete to have a porosity level of 15% to 30%[2]. The porous concrete performance will be determined by several aspects, including the porosity level and aggregate size used. Therefore, this study aims to analyze the influence of porosity level and aggregate size on the mechanical properties of porous concrete and its design recommendations based on the required capacity.

2. Methodology

2.1. Mixture Proportion
Obla, 2010[3], in his research, has carried out the procedure of calculating the mixture proportion of porous concrete by determining the volume of each material, namely the aggregate volume, cement, and water. The materials used in this study were coarse aggregate, Ordinary Portland Cement, water, and superplasticizer, with w/c of 0.4. The porosity levels analyzed in this study were 15% and 20% with the aggregate sizes selected were 10 mm and 20 mm. The mixture proportions obtained are shown in Table 1.

| Composition       | Mixture Proportion |
|-------------------|--------------------|
|                   | BP-1               |
|                   | BP-2               |
| Porosity (%)      | 15%                |
|                   | 20%                |
| Coarse Aggregate  | 1487               |
| (kg)              | 1487               |
| Cement (kg)       | 252                |
|                   | 182                |
| Water (kg)        | 101                |
|                   | 73                 |
| Superplasticizer (kg) | 1.8            |
|                   | 1.4                |

2.2. Sample and Testing Procedures
Material tests were carried out based on [4] for water content, [5] for specific gravity and absorption, [6] for unit weight and voids, [7] particle size analysis, and [8] for aggregate abrasion resistance using Los Angeles machine.

Samples were cast in cylindrical steel molds of 100 mm diameter x 200 mm height and made using a pan-type concrete mixer. Firstly, the aggregate and cement were dry mixed for 30 seconds. The water mixed with superplasticizer were then gradually added into the mixer and mixed for a further 3 minutes. After it was thoroughly mixed, the mixture was poured into the mold in three layers and compacted with hand rodding 25 times for each layer. The freshly compacted samples were covered with a plastic sheet for the first 24 hours and then demolded. The samples were cured in water until the porous concrete samples ready for testing.
Compressive strength, flexural strength, and splitting tensile strength tests were carried out at the age of 7 and 28 days for each test sample. The shrinkage test was carried out from a 1-day old test sample to a 7-day old test sample. The compressive strength test is performed based on [9], with cylindrical samples measuring 15 cm x 30 cm. The flexural strength test is carried out based on [10], with a beam-shaped test sample measuring 7.5 cm x 7.5 cm x 25 cm. The split strength test is carried out based on [11], with cylindrical test samples measuring 15 cm x 30 cm. The shrinkage test was carried out based on [12], with a beam-shaped test sample measuring 7.5 cm x 7.5 cm x 25 cm.

2.3. Pervious Concrete Pavement Design
The design of porous concrete pavement thickness refers to [13]. It considers two aspects, namely, the strength and hydrological aspects. In the aspect of strength, according to [3], it is stated that there is no definitive method for determining the thickness of porous concrete based on the desired strength. However, the thickness commonly used according to the required strength ranges from 150 mm to 300 mm.

In the hydrological aspect, various kinds of supporting data are needed. First, rainfall with a 2-year return period, as the planned rain to be accommodated. Then, porous concrete water's storage capacity determines the right level of porosity for the planned rain to be adapted—last, the type of soil that will choose the use of the subbase layer or not.

After that, the thickness of the layer was calculated by the following equation

\[ S_c = (P_p \times T_p) + (P_s \times T_s) \]  

Where:
- \( S_c \) = Storage capacity (mm/day)
- \( P_p \) = Pervious pavement porosity (%)
- \( T_p \) = Pervious pavement thickness (mm)
- \( P_s \) = Subbase layer porosity (%)
- \( T_s \) = Subbase layer thickness (mm)

The calculation started with determining the storage capacity based on the 2-year return period rainfall in the area of application of porous concrete. The porosity level was determined based on the material's plan to be used in each layer. Finally, in order to determine the thickness, iterations were carried out to adjust the thickness between the porous concrete layer and the subbase layer according to each layer's acceptable range, i.e. 150 mm - 300 mm for each layer.

3. Results

As explained above, the results of compressive strength, flexural strength, splitting tensile strength, and shrinkage of porous concrete were analyzed based on two parameters, namely the maximum aggregate size (MSA) of aggregate and the porosity level.

3.1. Compressive Strength
The effects of maximum aggregate size (MSA) and porosity level on the compressive strength of porous concrete are shown in Figure 1 and Figure 2, respectively. Based on Figure 1, it can be seen that samples with a maximum aggregate size (MSA) of 10 mm are stronger than samples with a maximum aggregate size (MSA) of 20 mm with a compressive strength
value of 7.23 MPa for 10 mm MSA and 7 MPa for MSA 20 mm for 7 days concrete age. As for the concrete age of 28 days, porous concrete with 20 mm MSA is stronger than the concrete with 10 mm MSA. Even more, at the age of 28 days, the test results have decreased from the concrete age of 7 days. For porous concrete with 10 mm MSA with 28 days age, a value of 5.24 MPa was obtained, while for porous concrete with 20 mm MSA with 28 days, a value of 5.94 MPa was obtained. As we can see from Figure 1, at the age of 7 days, porous concrete with 10 mm aggregate size has higher compressive strength than that of 20 mm, but, at the age of 28 days, porous concrete with 20 mm aggregate size has the higher compressive. This condition might be due to an inadequate compaction process.

Then, in Figure 2, it can be seen that the compressive strength at the porosity is 15% higher than the porosity level of 20%, with the acquisition of 7 MPa for the porosity level of 15% and 4.87 MPa for the porosity level of 20%. Therefore, it can be concluded that the lower the porosity level, the higher the compressive strength value of porous concrete. This condition might occur due to differences in the cement composition used, at a porosity level of 15%, more cement use of 69.93 kg/m³ compared to the porosity level of 20%, which can cause a weakening of the quality of the binding between the aggregates.

**Figure 1. Effect of Aggregate Size on Porous Concrete Compressive Strength**

**Figure 2. Effect of Porosity on Porous Concrete Compressive Strength**
3.2. Flexural Strength

The effects of maximum aggregate size (MSA) and porosity level on the flexural strength of porous concrete are shown in Figure 3 and Figure 4, respectively. Based on Figure 3, it can be seen that porous concrete with 10 mm MSA has a flexural strength of 1.55 MPa at 7 days, while porous concrete with 20 mm MSA has a flexural strength of 0.85 MPa. At the age of 28 days, porous concrete with 20 mm MSA has a flexural strength value of 1.01 MPa.

Based on Figure 4, it can be seen that both porous concretes at 7 days with porosity level of 15% and 20% have very low flexural strength which is < 1 MPa. Therefore, it can be concluded that young porous concrete cannot withstand the bending moment given by the weight of the test equipment. However, at 28 days, porous concrete with a porosity level of 15% has a flexural strength of 1.01 MPa.

This condition indicates that the smaller the maximum aggregate size (MSA) and the smaller the porosity level, the porous concrete would have better flexural strength value. Porous concrete achieved optimum flexural tensile strength at 28 days. This condition may occur due to the density of porous concrete using a smaller aggregate size, as well as the use of more cement at a porosity level of 15%, which results in a stronger and more even bonding between aggregates.

![Figure 3. Effect of Aggregate Size on Flexural Strength](image1)

![Figure 4. Effect of Porosity on Flexural Strength](image2)
3.3. Splitting Tensile Strength

The effects of maximum aggregate size (MSA) and porosity level on the splitting tensile strength of porous concrete are shown in Figures 5 and 6, respectively. Based on Figure 5, it can be seen that porous concrete with 10 mm MSA has a tensile strength value of 0.99 MPa at 7 days, while porous concrete with 20 mm MSA has a tensile strength value of 0.66 MPa. At 28 days, porous concrete with 20 mm MSA has a tensile strength of 0.93 MPa.

Based on Figure 6, it can be seen that porous concrete with a porosity level of 15% has a split tensile strength value of 0.66 MPa at 7 days of age, while porous concrete with a porosity level of 20% has a tensile strength value of 0.44 MPa. At the age of 28 days, porous concrete with a porosity level of 15% has a concrete tensile strength of 0.93 MPa.

This condition indicates that the smaller the maximum aggregate size (MSA) and the smaller the porosity level, the porous concrete will have a better split tensile strength value. Porous concrete will achieve optimum split tensile strength at 28 days. This condition might be due to the density of porous concrete that uses smaller aggregate sizes and the use of more cement at a porosity level of 15%, which results in stronger and more evenly binding between aggregates.

![Effect of Aggregate Size on Splitting Tensile Strength](image-url)

*Figure 5. Effect of Aggregate Size on Splitting Tensile Strength*
3.4. Drying Shrinkage

The effects of maximum aggregate size (MSA) and porosity level on the drying shrinkage of porous concrete are shown in Figures 7 and 8, respectively. Based on Figure 7, it can be seen that samples with a size of 20 mm and a porosity level of 15% have a greater shrinkage value compared to samples that have a size of 10 mm and a porosity level of 15%. Thus, it can be said that the greater the aggregate size used, the greater the shrinkage value experienced by porous concrete. This condition may be due to the larger porous shape when using a larger aggregate size to cause a more massive hydration process, which will then increase the shrinkage value compared to porous concrete that uses smaller aggregates.

Based on Figure 8, it can be seen that samples with a size of 20 mm and a 15% porosity have a greater shrinkage value compared to samples that have a size of 20 mm and a porosity of 20%. This condition indicates that the smaller the porosity level, the greater the shrinkage value experienced by porous concrete. This condition may be due to the more significant cement content in porous concrete with a porosity level of 15%, which causes a more massive hydration process than porous concrete with a porosity level of 20%, which contains less cement.
3.5. Design Recommendation

In terms of design recommendations, it is necessary to know the field conditions where the porous concrete pavement will be applied, such as average rainfall and soil conditions. The type of material, the proportion of the mixture, the size of the aggregate, and the level of porosity of porous concrete need to be known. Based on the Indonesia Ministry of Public Works and Housing data, Depok City has an average rainfall of 119.76 mm/day, which is then rounded off to 120 mm/day. Then, based on data from the Depok City Government, it is known that the majority of soil types in Depok City are red latosol soil, with an absorption capacity of 5.47-19.18 mm/day. When compared with the average rainfall of Depok City, the red latosol soil is less permeable.

Based on the results carried out in the laboratory as explained above, it was concluded that a porosity level of 15% and an aggregate size of 10 mm used in porous concrete produced better mechanical properties. Therefore, a design recommendation was made in the form of technical drawings that illustrate the material, dimensions, and road sections that can be applied. These images are shown in Figures 9 and 10 are cross-section detail technical drawings of porous concrete pavement to accommodate 120 mm/day of rainwater with a thickness of 200 mm porous concrete layer and 225 mm subbase layer, along with subsurface drainage pipes and impervious liner layers.

The subgrade layer is a surface that has been prepared to be used as road work. This preparation is carried out using excavation or landfill, which is then compacted. This layer is also the basis for laying out pavement parts and other construction.

Then, after the subgrade layer has been compacted, the impervious liner is installed. Impervious liner is a layer made of plastic or synthetic material that is flexible and fluid resistant. It is used to coat the wall or bottom that serves to provide secondary containment in the event of a leak. This layer needs to be installed because the soil conditions in Depok's city are less permeable than the rainfall received so that if some water enters the ground, it can cause blockages.

After the impervious liner was installed, the subbase layer work can already be started. The subbase layer is the part of the pavement that lies between the foundation layer and the subgrade. In the case of porous concrete pavement, the subbase layer is located between the surface layer and the subgrade layer. This layer serves to spread the burden to the subgrade's extent, absorb and deliver water, prevent the entry of the subgrade to the surface layer, protect the subgrade, and become the lower layer in the making of pavement.
Based on Figure 11, porous concrete pavement captures water through the surface layer, which will then be forwarded to the subbase layer, which will then be accommodated inside the subbase layer. In this research, it is necessary to make drainage below the surface due to less permeable soil conditions so that the function of porous concrete pavement is only as a reservoir of water, which then, at a certain height, the water will flow through a pipe that has been perforated.

4. Conclusions
This is a preliminary research to understand the effect of aggregate size and porosity on the mechanical properties of pervious concrete. This research concludes that the smaller the porosity level of porous concrete, the greater the splitting tensile strength, flexural strength, and porous concrete's shrinkage value. The use of smaller size aggregate in porous concrete produced better results of splitting tensile strength and flexural strength. It is also worth noting that the compressive strength is affected by the moisture content in the concrete, mixing procedure, and compaction method. Finally, the porous concrete pavement recommended design for Depok City with an average rainfall of 120 mm/day with less permeable soil conditions was drawn in Figures 9 and 10. Porous concrete layer with a 15% porosity level, with 200 mm thickness, will be required for Depok City. The subbase layer with a 40% porosity level, with 225 mm thickness, along with HDPE pipe with 100 mm diameter, and impervious liner layers 0.38 mm thick, will also be required. Further research on the porous concrete design based on field study is urgently needed to prove the recommended design.
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