The Effect of Styrene Butadiene Rubber Latex to the Strength and Permeability Performance of Pervious Concrete using Recycled Aggregate

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Abstract. Based on its geographical location, Indonesia is a country with high annual rainfall that causes the country to face a number of environmental problems, especially in urban areas. Reduced catchment areas due to changes in land use into residential and industrial areas, causing surface runoff problems and groundwater level declines. The use of pervious concrete as an alternative to environmentally friendly pavement can overcome these environmental issues. Nevertheless, pervious concrete has low strength due to weak bonding between aggregates as pervious concrete uses little or no fine aggregate so that it is only fastened by paste and produces voids between aggregate. Styrene butadiene rubber (SBR) latex was proposed in this study to improve bonding between aggregates and increase the strength of pervious concrete. 0%, 5% and 10% SBR latex by weight of cement were added in pervious concrete mixture to investigate the effect of SBR latex to the strength and permeability performance of pervious concrete to drain stormwater into the soil. Recycled coarse aggregate also used in the experiment to promote sustainable construction. The results showed that SBR latex increased the compressive strength of pervious concrete. However, the use of SBR latex also decreased the void ratio and permeability of pervious concrete

keywords: pervious concrete, recycled aggregate, SBR latex, void ratio, compressive strength

1. Introduction
Global warming is mostly caused by population growth, urbanization, and wasteful use of natural resources. The impermeable nature of most pavements contributes to a rise in surface runoff issues and stormwater pollution. Furthermore, the use of groundwater as a natural thermostat to regulate heat and moisture in cities is reduced, resulting in greenhouse and hot land impacts [1]. Pervious concrete is an environmentally friendly alternative to traditional pavements that have a low fine aggregate content and a high void ratio, allowing water to penetrate into the soil and reducing surface runoff [2]. The void ratio in pervious concrete is an important factor to keep in mind when building pervious pavement. Controlling the amount of water and cementitious material used, as well as utilizing only a small amount of fine aggregate to provide enough void for stormwater to drain through the pavement. The US Environmental Protection Agency (EPA) has designated suitable pervious concrete as a Best Management Practice for first-flush pollution prevention and storm management [3]. Pervious concrete is most commonly used in low-traffic areas such as parking lots,
residential roads, driveways, and walkways to address water table issues, making it a low-impact, ecologically friendly, and long-lasting pavement alternative [4,5]. Pervious concrete has a lesser strength than standard impermeable concrete pavement due to its large void content, and is thus only utilized for light traffic loads. There has been a lot of research done to increase the strength of pervious concrete. The vacancy ratio of pervious concrete, on the other hand, is heavily influenced by its constituent material. The void ratio and strength of pervious concrete are influenced by aggregate particle size, binder properties, and aggregate volume [1,6-8].

As pervious concrete has weak bonds between aggregate because they glued together only by cement paste, it is necessary to improve pervious concrete strength without compromising permeability performance. Styrene Butadiene Rubber (SBR) Latex was proposed to resolve the weak bonding issue between aggregate in pervious concrete. The utilization of recycled aggregate concrete was also proposed to promote sustainable construction as the amount of concrete waste continues to rise. This experiment is required evaluate the effect of SBR latex to the strength and permeability performance, especially void ratio and permeability of pervious concrete using recycled aggregate.

2. Materials and Methods

Pervious concrete is a concrete with voids that allows water to pass through and infiltrate into the soil. The void ratio is greatly influenced by the material properties used in the mix design of pervious concrete. To evaluate the strength and permeability performance of pervious concrete that utilize recycled coarse aggregate and styrene butadiene rubber latex, several materials is used in the mix proportion.

2.1. Materials Used

Void is the main characteristic of pervious concrete as it let water to drain so that surface runoff problems in urban areas can be solved. The void in the pervious concrete was created by the absence of sand in the mix proportion. Cement to aggregate ratio was set to 1:4, while the water to cement ratio was arranged to 0.27. In addition, SBR latex were also used to improve bonding between aggregate as it only affixed by cement paste that prone to crack, causing pervious concrete to have low strength.

2.1.1. Aggregate. To compare the effect of recycled aggregate on the strength and permeability performance of pervious concrete, recycled coarse aggregate reclaimed and natural coarse aggregate were used in the experiment with the size of 0.5 – 1 cm. The recycled aggregate was reclaimed from concrete waste with compressive strength around 300 kg/cm2 of its parent concrete. The physical properties of aggregate are listed in Table 1. Recycled coarse aggregate has lower unit weight and specific gravity, and higher absorption compared to natural coarse aggregate. These properties indicate that recycled aggregate has lower quality compared to natural coarse aggregate due to attached hardened mortar on the recycled aggregate, make it more porous and absorptive.

| Table 1. Physical properties of aggregate |
|-----------------------------------------|
| Properties                         | Aggregate Size |
|                                      | NCA            | RCA            |
| Unit weight (gr/cm3)               | 1.347          | 1.242          |
| Specific gravity                   | 2.775          | 2.390          |
| Absorption (%)                     | 5.013          | 8.153          |

*NCA = Natural Coarse Aggregate
*RCA = Recycled Coarse Aggregate

Cement. Portland composite cement met the SNI 7064:2064, which include in the blended hydraulic cement of ASTM C595-03 was used in the mixing of pervious concrete.
2.1.2. Styrene Butadiene Rubber Latex. A polymeric admixture SBR based emulsion latex was used in the experiment to improve bonding between aggregate and enhance the strength of pervious concrete. 0%, 5%, and 10% of SBR Latex by the mass of cement were added in the mix of pervious concrete.

2.2. Mix Design
A series of experiment were conducted to investigate the effect of SBR latex and the utilization of recycled coarse aggregate to the strength and permeability performance of pervious concrete. The mix proportion of pervious concrete are listed in Table 2.

| Table 2. Mix design of pervious concrete |
|----------------------------------------|
| Mix ID | Aggregate type | W/C | Cement (kg) | Aggregate (kg) | SBR Latex (%) |
|--------|----------------|-----|-------------|----------------|---------------|
| R0S1   |                | 260 | 1347        | 0%             |               |
| R0S2   | NCA            | 0.27| 260         | 1347           | 5%            |
| R0S3   |                | 260 | 1347        | 10%            |               |
| R1S1   |                | 260 | 1242        | 0%             |               |
| R1S2   | RCA            | 0.27| 260         | 1242           | 5%            |
| R1S3   |                | 260 | 1242        | 10%            |               |

2.3. Sample Preparation
The samples were prepared according to ACI 522 for pervious concrete using cylinder specimen with \( \phi 100 \text{mm} \times 200\text{mm} \) size for compressive strength test and permeability test. Prior to compressive strength test and permeability test, the specimens were cured for 7 days after casting.

2.4. Test Methods
Several tests were conducted to evaluate the strength and permeability of pervious concrete using recycled coarse aggregate with the addition of SBR latex. Void ratio test was performed for fresh pervious concrete, while permeability test and compressive strength test were conducted at age 28 day.

2.4.1. Pervious Concrete Density. Density is the main parameter that show the characteristic of concrete. Concrete with higher density has a tendency to produce higher strength [9]. This behavior also applies for pervious concrete as previous research found that the compressive strength of pervious concrete increases with the increase of its density [10, 11]. However, because of the variation of aggregate density and angularity, the accurate correlation between density and compressive strength of pervious concrete is difficult to determine [11]. A side from that, compaction level of concrete also affects the density of pervious concrete.

2.4.2. Void Ratio. ASTM C1688 was used to calculate the void ratio of pervious concrete. Void ratio is the ratio of the volume of voids to the volume of concrete specimen. According to ASTM C1688, the void ratio is determined as equation 1.

\[
\text{Void ratio (\%)} = \frac{\rho - D}{T} \times 100
\]

Where, \( D = (\text{Mc-Mm})/\text{Vm} \) (Density)
\( \text{Mc} = \) mass of measure filled with concrete
\( \text{Mm} = \) net mass of concrete by subtracting mass of measure
\( \text{Vm} = \) volume of measure
\( T = \text{Ms}/\text{Vs} \) (Theoretical Density)
\( \text{Ms} = \) total mass of materials batched
\( \text{Vs} = \) total absolute volume of materials
2.4.3. **Permeability Test.** Using cylinder concrete specimen with dimension of $\phi 100 \times 200$ mm, permeability test was performed according to ACI-522R. It illustrates the ability of water to penetrate into the pervious concrete as a medium which denoted as the permeability coefficient ($k$) using falling head method.

2.4.4. **Compressive Strength Test.** To evaluate the effect of SBR latex on the strength of pervious concrete using recycled coarse aggregate, compressive strength of concrete was conducted at age 28 days. It informed the ability of concrete to withstand compressive axial forces as the primary mechanical properties of concrete.

3. **Result and Discussion**

3.1. **Pervious concrete density**

The density of fresh pervious concrete using natural coarse aggregate and recycled coarse aggregate are listed in Table 3 and Table 4, respectively. It shows that SBR latex increased the density of fresh pervious concrete for both type of aggregate. These facts then further affected the other physical and mechanical properties of pervious concrete. The density of hardened pervious concrete is illustrated in Fig 1 that shows the same trend as fresh pervious concrete.

| Mix ID | Mix Design  | Mc  | Mm  | Vm (m$^3$) | Ms  | Vs (m$^3$) | Density (D) (kg/m$^3$) | Theoretical Density (T) (kg/m$^3$) |
|--------|-------------|-----|-----|------------|-----|------------|------------------------|-----------------------------------|
| ROS1   | NCA, SBR Latex 0% | 7.210 | 1.63 | 0.0048 | 117 | 0.084 | 1163.95 | 1391.16 |
|        |              | 7.110 | 1.63 | 0.0048 | 117 | 0.084 | 1143.10 | 1391.16 |
|        |              | 7.150 | 1.63 | 0.0048 | 117 | 0.084 | 1151.44 | 1391.16 |
| ROS2   | NCA, SBR Latex 5% | 7.310 | 1.63 | 0.0048 | 118 | 0.084 | 1184.81 | 1401.31 |
|        |              | 7.320 | 1.63 | 0.0048 | 118 | 0.084 | 1186.90 | 1401.31 |
|        |              | 7.306 | 1.63 | 0.0048 | 118 | 0.084 | 1183.98 | 1401.31 |
| ROS3   | NCA, SBR Latex 10% | 7.450 | 1.63 | 0.0048 | 119 | 0.084 | 1214.02 | 1411.46 |
|        |              | 7.680 | 1.63 | 0.0048 | 119 | 0.084 | 1261.99 | 1411.46 |
|        |              | 7.702 | 1.63 | 0.0048 | 119 | 0.084 | 1266.58 | 1411.46 |

3.2. **Void Ratio**

Void ratio is one of the most important tests in pervious concrete. Pervious concrete has many pores that enable to drain water to the void of concrete. Higher ratio of void ratio indicates higher volume of void that leads to increase the permeability of pervious concrete, and conversely reduce its compressive strength. Figure 2 illustrate the effect of adding SBR latex in mix proportion to the void ratio of pervious concrete. It shows that the void ratio decreased as the SBR latex percentage increase. The figure also informs that utilizing recycled coarse aggregate increased the void ratio of pervious concrete due to the presence of hardened mortar attached to the original aggregate made it the concrete became more porous.
### Table 4. Density of fresh pervious concrete using recycled coarse aggregate

| Mix ID | Mix Design | Mc  | Mm  | Vm (m³) | Ms  | Vs (m³) | Density (D) (kg/m³) | Theoretical Density (T) (kg/m³) |
|--------|------------|-----|-----|---------|-----|---------|---------------------|-------------------------------|
| R1S1   | RCA, SBR Latex 0% | 6.794 | 1.63 | 0.0048 | 110.35 | 0.084 | 1077.18 | 1307.05 |
|        |            | 6.700 | 1.63 | 0.0048 | 110.35 | 0.084 | 1057.57 | 1307.05 |
|        |            | 6.530 | 1.63 | 0.0048 | 110.35 | 0.084 | 1022.11 | 1307.05 |
| R1S2   | RCA, SBR Latex 5%  | 6.819 | 1.63 | 0.0048 | 111.20 | 0.084 | 1082.39 | 1317.20 |
|        |            | 6.879 | 1.63 | 0.0048 | 111.20 | 0.084 | 1094.81 | 1317.20 |
|        |            | 6.849 | 1.63 | 0.0048 | 111.20 | 0.084 | 1088.60 | 1317.20 |
| R1S3   | RCA, SBR Latex 10% | 6.890 | 1.63 | 0.0048 | 112.06 | 0.084 | 1097.20 | 1327.35 |
|        |            | 6.903 | 1.63 | 0.0048 | 112.06 | 0.084 | 1099.92 | 1327.35 |
|        |            | 6.910 | 1.63 | 0.0048 | 112.06 | 0.084 | 1101.38 | 1327.35 |

### Figure 1. Density of hardened pervious concrete
3.3. Permeability
To evaluate the permeability performance of pervious concrete, the permeability test according to ACI 522R were performed at age 28 days using falling head method. The result indicates that the addition of SBR Latex reduced its permeability coefficient \( k \) as shown in Figure 3, which is in accordance with the void ratio results.

3.4. Compressive Strength
Although permeability performance is the main goal of creating pervious concrete to solve surface runoff problems, however, the strength of pervious concrete is an important factor should not be ignored, especially when using pervious concrete as road pavement. The result of compressive strength test of pervious concrete is illustrated in Figure 4. It reveals that SBR latex improves the compressive strength of pervious concrete up to 47.5% when using natural coarse aggregate and...
65.87% when using recycled coarse aggregate. However, Figure 4 also indicates that the compressive strength of pervious concrete reduced when using recycled coarse aggregate compared to natural coarse aggregate.

![Figure 4. Compressive strength of pervious concrete](image)

The correlation between void ratio and compressive strength is drawn in Fig 5. It illustrates how void ratio greatly influenced the compressive strength of pervious concrete. It declares that higher void ratio reduces the compressive strength of pervious concrete.

![Figure 5. Void ratio vs compressive strength of pervious concrete](image)

4. Conclusions

The experiment evaluated the effect of SBR latex on the strength and permeability performance of pervious concrete using recycled aggregate. The following conclusions are derived from the results:

1. Pervious concrete made of recycled aggregate proved to have higher void ratio compared to pervious concrete using natural coarse aggregate
2. The addition of Styrene Butadiene Rubber Latex reduced the void ratio and permeability of pervious concrete
3. 10% of SBR latex added in the mix of pervious concrete improved the compressive strength of natural coarse aggregate and recycled aggregate pervious concrete up to 47.5% and 65.87%, respectively, which proved that SBR Latex strengthened the bonding between aggregate
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