The development of permeable pavement from demolished construction waste

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Abstract. In Indonesia, paving blocks are one of the most extensively used building materials. Paving blocks are ideal for making roads, parks, and parking lots because they are easy to install, durable, and weather-resistant. The high demand for paving blocks contributes to the increasing demand for aggregate as the main material for paving blocks. This has an indirect impact on the environment. On the other hand, building demolition waste is increasing. The majority of these building materials are non-biodegradable, such as concrete, plaster, brick walls, and tiles, which could harm the environment. Therefore, this study aims to see the possibility of using demolished concrete, brick walls, and tiles as a substitute for the aggregate in the production of permeable paving blocks. Each substitute material is then sampled and evaluated with compressive strength and infiltration rate to find the most optimum permeable paving block design. Based on the analysis, permeable paving blocks that use concrete as a substitute for coarse aggregate have better permeability and compressive strength compared to paving blocks that use brick walls and tiles waste. This paving block has an infiltration rate of 858 mm/hour and compressive strength of 11.68 MPa which is suitable for use in the park.

1. Introduction
In recent years, the Indonesian government and the world have been aggressively implementing the recycling of wastes to produce new products to reduce the impact of global environmental harm. Infrastructure development is one of the biggest contributors to waste. Construction and demolition waste is generated every time there is a construction/demolition activity, such as the construction of roads, bridges, high rise buildings, renovation of buildings, etc. as shown in Figure 1. Most of these used building materials consist of non-degradable materials such as concrete, plaster, brick walls, tiles, and wood.

The increasing demand for concrete to meet the needs of infrastructure development around the world harms the environment. Construction and demolition waste management have become a major concern due to the increasing number of demolition waste materials, the decreasing number of waste disposal sites, increasing disposal and transportation costs, and most importantly the increasing environmental degradation which is contributing to the global climate crisis.

The climate crisis also increases the risk of flooding in Indonesia. The climate issue has resulted in changes in the duration of the season, where the rainy season is getting shorter while the dry season is getting longer. As a result, the intensity of rain increases while the number of rainy days decreases, thereby increasing the risk of flooding [1]. Furthermore, asphalt and concrete layers that have impermeable properties are being used in the construction of residential roads, parking lots, and parks.
The covered ground surface further increases surface runoff and increases waterlogging because water cannot infiltrate into the ground [2].

Figure 1. Unused construction demolition waste

One example of flood conditions due to changes in land cover is the flood that occurred in almost all areas of Semarang City in February 2021. Water inundated roads and also housing, including roads and housing that had used paving blocks as pavements. Whereas paving blocks are permeable pavements that function to reduce rainwater runoff [3,4]. However, the conditions in the field show conditions that are not ideal where inundation still occurs. This is possible because the paving blocks used have low permeability. Based on their ability to absorb water, paving blocks are divided into two categories, namely low permeable paving blocks and high permeable paving blocks. Paving blocks can be categorized as high permeable if they have an infiltration rate of more than 3 mm/s [5].

Based on the two main problems that have been mentioned, in this study, research was developed to utilize construction waste to be used in the manufacture of permeable paving blocks. The development of concrete or pavement by utilizing waste has been carried out by several researchers, especially recycled material waste. Some researchers use the concrete waste from building demolition as a substitute for coarse aggregate as a road pavement layer [6–8]. The results of this study indicate that the recycled aggregate can be used as a coarse base or sub-base on road pavements that are passed by light to medium volume vehicles such as residential roads or parking lots.

Besides being researched as a substitute for aggregate in road pavement layers, the use of concrete waste from the demolition of buildings is also used as a substitute for coarse aggregate in the manufacture of concrete [9]. In addition to conventional concrete, the use of this waste has also been investigated as a substitute for coarse aggregate in porous concrete [10]. In addition to concrete waste, asphalt pavement waste has also been investigated as a substitute for aggregate in the development of porous concrete [11].

Aside from being used as a coarse aggregate substitute, demolition building waste has also been studied as a fine aggregate. Ganiron uses building demolition concrete waste as a fine aggregate substitute in mortar mixtures [12]. Several studies have also been conducted to develop waste-based paving blocks. One of them is a study by Pratikto & A that uses concrete roof tile waste as a coarse aggregate substitute [13]. Aside from using construction waste, research is conducted by adding plastic or PET into the paving block mix [14-16].

The goal of this research is to develop environmentally permeable paving blocks that use building demolition waste instead of crushed stone as coarse aggregate. This permeable paving block development study was carried out by utilizing building construction demolition waste which was processed into several size ranges of recycled coarse aggregate. Infiltration test method modifications were also made to accommodate research needs. The results of this study are expected to produce a mixed design of permeable paving blocks that meet the specifications as a permeable pavement layer both in terms of permeability and strength.
2. Materials and Method

2.1. Materials
The development of permeable paving blocks is only focused on replacing coarse aggregate with recycled materials, so that other materials still use conventional paving block materials such as water, cement, and fine aggregate. The cement used was Portland cement with the brand name Semen Gresik and the sand used was Muntilan sands type with physical properties as shown in Table 1. The sand used in the study was sand that passed the size of 4.75 mm.

| No | Properties                  | Fine aggregate | Cement  |
|----|-----------------------------|----------------|---------|
|    |                             | Natural | SSD     |         |
| 1  | Specific gravity (kg/dm³)   | 2.309   | 2.230   | 3.150   |
| 2  | Diameters (mm)              | <4.75   | -       |         |
| 3  | Type of materials           | Muntilan sands | Semen Gresik |
| 4  | a. Loose bulk density (kg/dm³) | 1.640   | 1.467   | -       |
|    | b. Compacted bulk density (kg/dm³) | 1.685   | 1.685   | -       |
| 5  | Water absorption (%)        | 0.50    | 1.70    | -       |
| 6  | Clay and fine dust content (%) | 0.80    | 1.60    | -       |

2.2. Recycled coarse aggregates
The coarse aggregate used in this study of the development of permeable paving blocks is a substitute for crushed stone made from demolished concretes waste, brick walls waste, and tiles waste. The construction waste is sorted, crushed, and then sifted for later use as recycled aggregate as seen in Figure 2. In this study, the aggregate size used was aggregate that passed the size of 12.5 mm and retained 9.5 mm. The recycled aggregate is then tested for physical properties to be used later in the mix design calculation. The results of the physical properties test of this recycled aggregate can be seen in Table 2.

![Figure 2](image-url)

Figure 2. Recycled coarse aggregates (a) concretes waste (b) brick walls waste (c) tiles waste

2.3. Paving block design
Paving blocks have various shapes and colors with very varied sizes. The permeable paving block samples in this study were made in the shape of a square with a length of 200 mm, a width of 200 mm, and a height of 90 mm to make manufacturing and testing easier. The paving block samples were made from two different mixture designs for the outside and the inside layer, as shown in Figure 3. The outside only consisted of a mixture of water, cement, and fine aggregate with a ratio of 1 part of cement: 4 parts
of fine aggregates. While the inner circle with a diameter of 170 mm is made of a mixture of water, cement, fine aggregate, and recycled coarse aggregate with a ratio of 1 part of cement: 2 parts of fine aggregate: 2 parts of coarse aggregate. Details of the material composition used for each type of recycled coarse aggregate can be seen in Table 3.

Table 2. Physical properties of recycled coarse aggregates

| No | Properties                    | Demolished concrete | Demolished brick walls | Demolished Tiles |
|----|-------------------------------|---------------------|------------------------|-----------------|
|    |                               | Natural | SSD | Natural | SSD | Natural | SSD |
| 1  | Specific gravity (kg/dm³)     | 2.433   | 2.392 | 2.265 | 2.237 | 2.242 | 2.245 |
| 2  | a. Loose bulk density (kg/dm³)| 1.243   | 1.337 | 1.058 | 1.136 | 1.120 | 1.275 |
|    | b. Compacted bulk density (kg/dm³)| 1.314 | 1.388 | 1.132 | 1.218 | 1.135 | 1.336 |
| 3  | Water absorption (%)          | 4.38    | 4.93  | 4.27  | 4.40  | 0.00  | 6.27  |
| 4  | Clay and fine dust content (%)| 6.80    | 7.00  | 5.40  | 6.80  | 1.40  | 4.00  |
| 5  | Diameters (mm)                | 9.5 – 12.5 | 9.5 – 12.5 | 9.5 – 12.5 |

Figure 3. Dimension of model paving block

Table 3. The material composition of the mixed design

| Mix design code | Substitute coarse aggregate | Part                | Mix design ratio | Water cement ratio |
|-----------------|-----------------------------|---------------------|------------------|--------------------|
| BT              | Demolished concrete         | Inside layer        | 1 : 2 : 2        | 0.30               |
|                 |                             | Outside layer       | 1 : 4            | 0.30               |
| DB              | Demolished brick walls      | Inside layer        | 1 : 2 : 2        | 0.30               |
|                 |                             | Outside layer       | 1 : 4            | 0.30               |
| KR              | Demolished tiles            | Inside layer        | 1 : 2 : 2        | 0.30               |
|                 |                             | Outside layer       | 1 : 4            | 0.30               |

Based on the results of the physical properties test for each material, the volume requirements of the materials to make the mixture are calculated according to Table 3. Each mix design is made of 12 samples using a concrete mixer and paving block printer to ensure consistency in sample quality. All paving block samples were then cured for 28 days before infiltration rate and compressive strength were tested.

2.4. Test methods

Paving blocks that meet specifications for infiltration rate and compressive strength are required for this study. Therefore, the paving blocks that have been made need to be tested for the ability of these two things. The infiltration rate test was carried out using the equipment as shown in Figure 4. Four samples of paving blocks were set up on the equipment as in Figure 5, then the gaps between paving blocks were sealed to ensure that water only passed through the pores of the paving blocks. The infiltration rate is
calculated by recording the time it takes for the water to fall every 10 mm. The compressive strength test is carried out with compression test equipment as shown in Figure 6. This compressive strength test is carried out to find out which paving block samples made can meet which category of paving block uses.

Figure 4. The infiltration test equipment

Figure 5. Paving block set up in the infiltration test equipment

Figure 6. The compressive strength test
3. Results and Discussion

The results of the infiltration test for each paving block with substitute aggregate can be seen in Figures 7 to d. Figure 9. The graph of the comparison of the infiltration rates of the three concretes with substitute aggregates can be seen in Figure 10. It was found that paving blocks with recycled aggregate made from concrete had the highest infiltration rate. As a comparison, the infiltration rate is used when the water level is close to zero, paving blocks with substitute aggregate of concrete have an infiltration rate of 858 mm/hour. Meanwhile, paving blocks with substitute aggregates of brick walls and tiles are 284 mm/hour and 203 mm/hour, respectively. In general, these paving blocks already have a higher level of permeability than the general design rainfall intensity of 200 mm/hour.

Figure 7. Graph of the relationship between infiltration rate and water depth of the demolished concrete waste paving block

Figure 8. Graph of the relationship between infiltration rate and water depth of demolished brick walls waste paving block
Based on the results of the compressive strength test, it was found that paving blocks with substitute aggregate made from concrete have a compressive strength of 11.68 MPa, greater than brick walls and tiles which have a compressive strength of 7.54 MPa and 7.44 MPa, respectively. Based on the results of infiltration rate and compressive strength tests as shown in Table 4, it could be concluded that of the three substitutes for coarse aggregate, paving block with coarse aggregate made of concrete has better quality in terms of permeability and strength. This permeable paving block, which has a compressive strength of more than 10 MPa, is classified as a quality D paving block and could be used as a park pavement layer.
Table 4. Infiltration rate and compressive strength of the development permeable paving block

| Mix design code | Substitute coarse aggregate       | Compressive strength (Mpa) | Infiltration rate (mm/hour) |
|-----------------|----------------------------------|---------------------------|----------------------------|
| BT              | Demolished concrete              | 11.68                     | 858                        |
| DB              | Demolished brick walls           | 7.54                      | 284                        |
| KR              | Demolished tiles                 | 7.44                      | 203                        |

4. Conclusion
Based on the analysis of permeable paving block samples from demolished construction waste, it was found that permeable paving blocks that use concrete as a substitute for coarse aggregate have better permeability and compressive strength compared to paving blocks that use brick walls and tiles waste. This paving block has an infiltration rate of 858 mm/hour, which is higher than the general design rain. The compressive strength of paving blocks is 11.68 MPa which is suitable for use as a park pavement layer or is included in the quality category of paving block D.

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