Plastic Waste Conversion Reinforced with Rice Husk Ash and Red Stone Powder as Partial Sand Replacement for Paving Blocks Production

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Abstract. The conversion of plastic waste into economically valuable materials is an innovative way to reduce plastic waste in the environment. At the present study aimed to assess the compressive strength and water absorption capacity of paving blocks from plastic waste combined with rice hausk ash as sand partial replacement and red stone powder as its natural colorant. The specimen were casted in a 6 x 6 x 6 cm mold and pressed with a load of 6 tons using a mechanical pressing machine. The compressive strength and water absorption of paving block at different content of plastic powder and rice husk ash were investigated. The study revealed that paving blocks made by replacing sand with 40% of plastic powder and 5% of rice husk ash pigmented with red stone at the ages of 28 days have compressive strengths of 12.7 MPa with water absorption value of 3.75%. We recommend this paving block was suitable for non-traffic areas such as pedestrians, landscapes, and public walkways.

1. Introduction
The use of plastic recently has become a problem for the environment because it is very difficult to degrade naturally and its presence in the environment has gradually increased year by year. It is estimated that it need of 10-15 years to naturally degrade plastics in the environment. Most of the plastic used is single-use plastic which is then disposed of as a solid waste. The existence of plastic waste in the soil has an impact on decreasing soil fertility, while in the sea it has the potential to kill marine animals. Indonesia, which is one of the largest contributors to plastic waste in the sea, has committed to reducing 70% of marine plastic waste by 2025. To realize this commitment, various efforts have been conducted, including prohibiting the plastic supply for supermarket consumers, degradation using the incineration method, and conversion to economic value products.

Plastics waste treatment through conventional incineration has releasing toxic gases into the environment such as Polychlorinated biphenyls, Dioxins, Furan and Mercury [1]. The use of plastic waste to liquid fuel [2], enhance hot mix asphalt performance [3], and wax recovery [4] seems to be a good alternative way to reduce environmental damage, but it requires high costs. Innovation of the conversion of plastic waste into a product or product mixture that is economical but low cost has also been developed, such as for the design and manufacture of furniture [5] and paving blocks [6].

According to Indonesian National Standard (SNI) 03-0691-1996 [7], paving blocks are defined the building materials made from a mixture of water, aggregate and Portland cement or other adhesives with or without additional materials that do not reduce the quality of the paving blocks. Two
parameters commonly used to assess the suitability of using paving blocks are compressive strength and water absorption. The application of paving blocks for road, parking area, pedestrians and parks as well as other uses have a minimum average compressive strength of 35.0, 17.0, 12.5 and 8.5 MPa while the maximum average water absorption was 3, 6, 8 and 10%, respectively. Sand is one of the main materials in building and commonly used as fine aggregate in paving blocks production. The sand requirement is increases from year to year, but on the other hand the availability is tending to decrease. Therefore it is necessary to investigate other materials that can be used to sand replacement for building construction, including the paving blocks production. A numerous of recycled materials and by product of agriculture have been reported to have great potential to partially sand replacement in building materials without reducing their quality were sawdust ash [8], bagasse ash, and groundnut shell [9], sheet glass powder, crushed granite fine, and spent fire bricks [10]. In this study, eco-friendly concrete paving block production with the partial substitution of sand using plastic powder combined with rice husk ash as fine aggregate and inorganic pigments from red stone powder as natural inorganic pigment. Rice husk is a very reactive pozzolanic material, and can be used to improve the mechanical properties of paving blocks while red stone powder is used as a pigment to make the paving surface more attractive. Various strength parameters such as compressive strength and water absorption were investigated, and then compared to the strength of paving block according to SNI 03-0691 to assess its application area.

2. Materials and methods

2.1 Materials

The paving block material comprises river sand (passed in 5 mm of sieve), crushed stone (grain size of 5-10 mm), plastic powder, rice husk ash and red stone powder (passed in 1 mm sieve), Portland cement named as Tiga Roda and water. The plastic used was drinking water bottles, which is a type of polyethylene terephthalate (PET) obtained from plastic waste scavengers, while rice husk ash is collected from the rice milling industry in Bali, Indonesia. Performances of paving block materials are given in Figure 1, while physical properties of paving block materials are shown in Table 1.

![Figure 1. Paving block materials](image)

Table 1. Physical properties of paving block materials

| Properties          | Fine Aggregate | Coarse aggregate | Pigment |
|---------------------|----------------|------------------|---------|
|                     | River sand     | Plastic powder   | Rice husk | Crushed stone | Red stone  |
| Specific gravity (kg/m³) | 2.54           | 1.04             | 2.25     | 2.34          | 2.47       |
| Water absorption (wt. %) | 1.25           | 0.16             | 6.25     | 1.05          | 1.26       |
2.2 Plastics powder preparation

Plastic powder preparation was carried out by cutting the plastic into small pieces, and then put it in a drum container that already contain a little oil and heated while stirring manually until plastic slurry formed. The plastic slurry was poured into a plate container and allowed to cool at room temperature. Plastic solids are converted to plastic powder using a grinder machine completed with a 1 mm grain size sieve.

2.3 Paving block manufacture

Paving block was prepared in two steps. In the first step, paving blocks made with variation of plastic powder to sand ratio at other materials are constant. The mix proportion of paving block materials is shown in Table 2.

Table 2. Proportion of paving block materials for one sample tested.

| Mix | Fine aggregate (g) | Coarse aggregate (g) | Binder (g) | Pigment(g) |
|-----|--------------------|----------------------|------------|------------|
|     | Sand | Plastic powder | Crushed stone | Portland cement | Red stone powder |
| 1   | 550  | 0              | 180         | 180         | 90          |
| 2   | 495  | 55             | 180         | 180         | 90          |
| 3   | 440  | 110            | 180         | 180         | 90          |
| 4   | 385  | 165            | 180         | 180         | 90          |
| 5   | 330  | 220            | 180         | 180         | 90          |
| 6   | 275  | 275            | 180         | 180         | 90          |
| 7   | 220  | 330            | 180         | 180         | 90          |

The paving block material was placed in a pan, then manually stirred while added amount water of 12% (v / w) from the total material weight used. The paving block material was placed in a pan, then manually stirred while added amount water of 12% (v / w) from the total material weight used. The mixture was casted in paving block mould with dimension of 6 x 6 x 6 cm and then pressed at load of 6 tons using a mechanical pressing machine. Paving blocks are cured for 28 days under atmospheric conditions. In the second step, paving blocks are made following the previous procedure, but sand usage gradually replaced with rice husk ash while the composition of other materials is constant. The material compositions for paving block preparation in the second steps were presented in Table 3.

Table 3. Proportion of paving block materials for one specimen.

| Mix | Fine aggregate (kg) | Coarse aggregate (kg) | Binder (kg) | Pigment (kg) |
|-----|---------------------|-----------------------|-------------|--------------|
|     | Sand  | Plastic powder | Rice husk ash | Crushed stone | Portland cement | Red stone powder |
| 1   | 550   | 0              | 0.0          | 180          | 180         | 90          |
| 2   | 330   | 220            | 27.5         | 180          | 180         | 90          |
| 3   | 302.5 | 220            | 55.0         | 180          | 180         | 90          |
| 4   | 275   | 220            | 82.5         | 180          | 180         | 90          |
| 5   | 247.5 | 220            | 110.0        | 180          | 180         | 90          |
| 6   | 220   | 220            | 137.5        | 180          | 180         | 90          |
| 7   | 192.5 | 220            | 165.0        | 180          | 180         | 90          |
| 8   | 165   | 220            | 180          | 180          | 90          |
2.4 Testing

Paving blocks were assessed its quality after 28 days of cured with parameters test consist of the compressive strength and water absorption. The test result was compared to the compressive strength and water absorption which issued by SNI 03-0691-1996 to assess the usage feasibility. The compressive strength and water absorption values of paving blocks based on their application are listed in Table 4.

| Class | Compressive strength (MPa) | Water absorption (%) | Application            |
|-------|-----------------------------|----------------------|------------------------|
|       | Max. | Min. | Max. average |                      |
| A     | 40   | 35   | 3           | Road                  |
| B     | 20   | 17   | 6           | Parking area          |
| C     | 15   | 12.5 | 8           | Pedestrian            |
| D     | 10   | 8.5  | 10          | Parks and other users |

2.4.1 Compressive strength measurement

Paving block test sample with dimension of 6 x 6x 6 cm was put in a hydraulic compressive strength machine and pressed slowly with a certain load until the test sample breaks. Compressive strength was calculated using the formula:

\[ \text{Compressive strength (MPa)} = \frac{P}{A} \]

where \( \sigma \) = compressive strength (MPa), \( P \) = maximum pressing load (N) and \( A \) = surface area (cm²). The set-up for the compressive strength machine can be seen in Figure 2.
2.4.2 Water absorption measurement

Water absorption of paving block was carried out according to SNI 03-0691. The paving block test sample was immersed in water for 24 hours, then rinsed and left for about 2 hours while removing the water bound to the surface of the paving block using a cloth and then weighed (Ww). Paving block was dried in an oven at 105°C for 24 hours. Paving blocks were dried in an oven for approximately 24 hours at a temperature of 105°C until their weight at two times of weighing is less than 0.2% from the previous weighing (Wd). Water absorption of sample was calculated using formula:

\[
\text{Water absorption} \% = \left(\frac{W_w - W_d}{W_d}\right) \times 100\%
\]

where, Ww and Wd are the weight of paving block in wet and dry condition.

3. Result and Discussion

In this study, paving block were prepared in two versions, namely paving block in cubic formed with a size of 6 x 6 x 6 cm for tested samples and a tri-hexagonal paving block with dimensions of 19.7 x 9.6 x 6 cm. All paving block were presented in Figure 3.

![Figure 3. Paving block](image)

(a) Tested samples  (b) Paving block with red stone powder (c) Paving block without red stone powder

3.1 Compressive strength

Compressive strength is defined as the maximum load that causes the paving block to crack and is one of the parameters to assess its durability. Figure 4, show the relationship between the different substitution level of sand with powder plastic and the compressive strength of paving block. It is clear to observe that the compressive strength of a paving block decrease gradually when the amount of plastic was used to replace the sand increased. The decrease of compressive strength with increase rice husk ash addition caused by high porosity and low bulk density of rice husk ash. The compressive strength of paving block without sand addition was 25 MPa, and then decrease to 26.8 MPa, 19.3 MPa, 16.4 MPa, 14.9 MPa, 13.5 MPa, 12.9 MPa and 11.6 MPa when replacement level of sand by plastic powder were 10%, 20%, 30%, 40%, 50% and 60%, respectively. This finding is in line with ref [11]-[12], who reported that the compressive strength of paving block decreased with increasing plastic content.
According to SNI 03-0691: 1996, the compressive strength minimum value of paving block application for road, parking area, pedestrian and parks or other uses in successively were 35 MPa, 17 MPa, 12.5 MPa and 8.5 MPa. This indicates that the replacement of sand by plastic up to 50% results in paving blocks that meet the requirements used for pedestrians. A decrease in compressive strength can also be seen in the addition of rice husk ash as shown in Figure 5. It was observed that the compressive strength of paving block containing plastic powder 40% of total sand used was found to be 13.5 MPa in which decreased to 12.7 MPa, 10.1 MPa, 8.5 MPa, 6.4 MPa, 4.7 MPa, and 2.5 MPa with the replacement of 5%, 10%, 15%, 20%, 25% and 30% sand by rice husk ash. This finding consistent with earlier studies was carried out in ref [13], who reported that paving block without addition of rice husk ash have higher compressive strength than those with rice husk ash.

Figure 4. Effect of plastic waste substitution on compressive strength of paving block

Figure 5. Effect of rice husk ash substitution level on compressive strength of paving block
According to SNI 03-0691, the application of paving block for parking area has minimum compressive strength of 17 MPa whereas for pedestrian 12.5 MPa. It was indicated that the replacement of sand up to 5% by rice husk ash at the plastic content of 40% resulted in paving blocks suitable for pedestrians.

3.2 Water absorption

Water absorption is defined as the ability of paving block to absorb water when immersed in it. The durability of concrete mainly depends on its permeability. The high permeability causes the penetration of water molecules, sulphate ions, chloride ions and others harmful substances easier into the inner part of paving block and destroys their stability. It was clearly observed from Figure 6, that the water absorption value increased with increase the rice husk content within paving block. As presented in Table 1, rice husk ash has the highest water absorption compared to all aggregates used. This is a great contribute to the increase in water absorption of paving blocks. Water absorption of paving block was found to be 3.75%, 5.17%, 7.78%, 8.04%, 10.8%, 15.0% and 17.0% when sand replaced by rice husk ash at portion of 5%, 10%, 15%, 20%, 25% and 30%, respectively. This result is line with on ref [13], who reported that the water absorption properties of concrete increased with increasing percent replacement of sand with rice husk. In another study conducted by Djamaludin et al. (2020) who used tea waste ash, also found that water absorption from paving blocks increased with increasing tea ash content [14].

![Figure 6. Effect of rice husk ash substitution on water absorption of paving block](image)

According to SNI 03-0691, paving block with the maximum average water absorption equal to 8% are classified into C class (suitable for pedestrian or sidewalks application). Based on the compressive strength and water absorption test results, that paving block which was made by sand partial replacement by plastic powder (40%) and rice husk ash (5%) meet the requirements for pedestrian applications.

4. Conclusion

Plastic waste reinforced with rice husk ash has great potential to be used as fine aggregate to replace sand partially in paving blocks production. Paving blocks were made by replacing sand with 40% of plastic powder and 5% of rice husk ash at the ages of 28 days have compressive strengths of 12.7 MPa.
with water absorption value of 3.75%. We recommend this paving block was suitable for non-traffic areas such as pedestrians, landscapes, and public walkways.

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