Paving block with product 1 material as a substitute of portland cement and landfill mining residue

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Abstract. This research aimed to determine the CaO and SiO$_2$ content in landfill mining residue and glass waste, variations of selected compositions in accordance with SNI 03-0691-1996 on Paving Block, and the best values of the selected composition variation as paving block raw material. The research consists of six test steps namely visible properties, size, compressive strength, water absorption, wear resistance, and sodium sulfate resistance test. X-Ray Fluorescence method was used to determine the value of CaO and SiO$_2$ content in landfill mining residue and glass waste. The CaO and SiO$_2$ content in landfill mining residue were 5.81% and 46.31%; glass waste values were 8.77% and 65.07%; the variations were landfill mining residue, glass waste, and product 1. Paving block composition variations 2, 3, 5 have met the SNI 03-0691-1996 classification of quality D, which is geared towards city park use and the paving block composition variation 4 with the classification of quality C, used for pedestrian walkways. The best values of the selected paving block composition are a compressive strength of 18.84 MPa; water absorption value of 3.41%; wear resistance value of 0.188 mm/min; and sodium sulfate resistance value of <1%.

1. Introduction
Waste is a serious problem in a thriving and developed city. The increasing population growth will affect the amount of waste generation[1]. One of the cities that experienced this problem is Kediri City. The increasing amount of waste generation will require more land to accommodate the waste[2]. For example, Klotok Landfill Kediri City has very limited land for landfill, so the provision of land for landfill becomes the main problem in waste management in Kediri City[3]. Considering the problem of land limitations for landfill, then there should be proper handling of waste so that the impact caused to the environment can be minimized[4]. Several technologies for handling waste in the landfill include composting, thermal cracking, paving block, brick, and other technologies that implement the principle of reduce, reuse, and recycle (3R).

In this research, paving block was tested and compared with SNI 03-0691-1996 [5] on paving block The physical property tests values and sodium sulphate resistance test values that best suit the physical properties criteria of SNI 03-0691-1996 were chosen as the best variation of landfill soil as coarse aggregate and glass waste as fine aggregate. This is done to reduce landfill soil in the passive zone and extend the life of the landfill, as well as to reduce glass waste in the glass-making industry.

2. Research Methods
2.1. Ingredients
The materials used were Type 1 cement (Ordinary Portland Cement), product 1, fine aggregate (glass waste), coarse aggregate (landfill mining residue), sand, gravel, and water.
2.2. Variations in the composition of paving block raw materials

| Code | Variation | Composition |
|------|-----------|-------------|
|      |           | Coarse Aggregate | Fine Aggregate | Cement |
|      |            | Residue | Gravel | Glass Waste | Sand | Portland Cement | Product 1 |
| (%) | (g) | (%) | (g) | (%) | (g) | (%) | (g) | (%) | (g) |
| 1   | 0   | 0   | 0   | 0   | 80  | 2240 | 20  | 560 | 0  | 0  |
| 2   | 5   | 140 | 35  | 980 | 5   | 140  | 35  | 980 | 15 | 476 |
| 3   | 5   | 140 | 35  | 980 | 5   | 140  | 35  | 980 | 10 | 280 |
| 4   | 5   | 140 | 35  | 980 | 5   | 140  | 35  | 980 | 5  | 84  |
| 5   | 5   | 140 | 35  | 980 | 5   | 140  | 35  | 980 | 15 | 476 |

2.3 Data analysis

Data analysis in this research employed the comparative descriptive method, which was implemented by comparing paving block quality test results from this research with the National Quality Standard (SNI) 03-0691-1996 on Paving Block. There are 4 classifications of quality, namely quality A for roads, quality B for parking lots, quality C for pedestrians, and quality D for parks and other uses.

3. Result and Discussion

3.1. CaO and SiO₂ Content on residual landfill mining and glass waste as raw material for casting paving block

CaO and SiO₂ content in landfill mining residue and glass waste can be seen in Table 2.

| No. | Name                        | Chemical compound | Average       |
|-----|-----------------------------|-------------------|---------------|
| 1   | Landfill mining residue     | CaO               | 5.81% ± 0.161 |
|     |                             | SiO₂              | 46.31% ± 0.235|
| 2   | Glass waste                 | CaO               | 8.77% ± 0.111 |
|     |                             | SiO₂              | 65.07% ± 0.250%

Table 2 shows the average values of CaO and SiO₂ content in landfill mining residue. If the CaO content of the paving block is small, then the compressive strength value will decrease. However, if the CaO content is excessive, then the product sample becomes not sturdy and cohesive due to decreased attachment between the raw material particles in paving blocks. This is unlike what happens with SiO₂ content, which is high in paving block. The more the content, the greater the compressive strength value and the smaller the water absorption test value. This happens because the large amount of SiO content will cause the porosity of the material to get smaller, causing water absorption to decrease [3].

3.2. Paving block quality test based on SNI 03-0691-1996

3.2.1. Visible properties. The observation of paving blocks was performed visually and thoroughly. A paving block is considered to be good if they meet the SNI 03-0691-1996 quality standard, where the desirable paving block has a flat surface, no cracks and defects, and the corners and ribs are not easily mashed with the strength of fingers. In this research, all paving block products have good visible properties.
3.2.2. Size. The results of paving block dimension measurement can be seen in Table 3.

Table 3 shows that all paving block sizes meet the quality standard, which is a minimum thickness of 60 mm with an 8% tolerance. Paving blocks of uniform size will simplify the installation process and will yield a flat surface. This can cause water absorption and groundwater infiltration to be maintained.

| Variation | Length (cm) | Width (cm) | Thickness (cm) |
|-----------|-------------|------------|----------------|
| 1         | 21 ± 0.00   | 10.5 ± 0.00| 5.56 ± 0.03    |
| 2         | 21 ± 0.00   | 10.5 ± 0.00| 5.56 ± 0.02    |
| 3         | 21 ± 0.00   | 10.5 ± 0.00| 5.61 ± 0.07    |
| 4         | 21 ± 0.00   | 10.5 ± 0.00| 5.56 ± 0.04    |
| 5         | 21 ± 0.00   | 10.5 ± 0.00| 5.58 ± 0.03    |

3.2.3. Compressive strength. The average value of compressive strength and the results of its classification are in accordance with SNI 03-0691-1996 quality standards on paving blocks, which can be seen in Table 4.

Table 4 shows that variation 4 has the best value at 18.84 ± 1.49 MPa with the classification of quality B. The raw or aggregate factor affects the low value of the compressive strength. The raw materials of landfill mining residue, glass waste, and product 1 all have SiO₂ content. The higher the SiO₂ content in the paving block, the greater the compressive strength. This is due because higher SiO₂ content will result in lower material porosity [3].

| Variation | Average compressive strength value (MPa) | SNI Classification 03-0691-1996 |
|-----------|------------------------------------------|----------------------------------|
| 1         | 28.18 ± 4.12                            | √                                |
| 2         | 9.96 ± 2.21                              | B                                |
| 3         | 15.73 ± 2.69                             | C                                |
| 4         | 18.84 ± 1.49                             | √                                |
| 5         | 9.69 ± 1.99                              | D                                |

3.2.4. Water absorption. The average compressive strength values and the classification results are in accordance with SNI 03-0691-1996 quality standards on paving blocks, which can be seen in Table 5.

Table 5 shows that variation 4 has the best value of 3.41 ± 0.426% with a classification of quality B. Factors affecting water absorption in paving block are the type and nature of materials, material size, degree of structure density in paving block, pore shape, and others [4]. Water absorption in a good paving block can increase water infiltration, thus maintaining ground water balance. It aims to
reduce inundation in flood-prone areas, because the installation of paving blocks does not use adhesive materials such as cement mixture [5].

3.2.5. Wear resistance. The average value of compressive strength and the results of its classification are in accordance with SNI 03-0691-1996 quality standards on paving blocks, which can be seen in Table 6.

| Variation | Average Wear Resistance Values (mm/min) | SNI Classification 03-0691-1996 |
|-----------|-----------------------------------------|----------------------------------|
| 1         | 0.040 ± 0.019                           | A                                |
| 2         | 0.254 ± 0.067                           | B                                |
| 3         | 0.220 ± 0.425                           | C                                |
| 4         | 0.189 ± 0.037                           | D                                |
| 5         | 0.282 ± 0.237                           |                                  |

Table 6 shows that variation 4 has the best value of 0.189 ± 0.037 mm/min with the classification of quality C. The use of raw materials of landfill mining residue, glass waste, and product 1 can affect the value of the size of the wear resistance. These raw materials produce cavities or pores on the surface of the paving block, which will quickly experience wear and fragileness when exposed to water abrasion or frictions.

3.2.6. Sodium sulphate resistance test
The average sodium sulfate resistance values and their classification according to SNI 03-0691-1996 quality standard on paving block can be seen in Table 7.

| Variation | Mean Sodium Sulfate Resistance Value (kg) | SNI Classification 03-0691-1996 |
|-----------|------------------------------------------|----------------------------------|
| 1         | 0.85 ± 0.212                             | <1%                              |
| 2         | 1.15 ± 0.212                             | >1%                              |
| 3         | 0.7 ± 0.141                              | <1%                              |
| 4         | 0.8 ± 0.141                              | <1%                              |
| 5         | 0.7 ± 0.141                              | <1%                              |

Based on Table 8, variation 2 has a value of >1%, while variations 1, 4, 3, and 5 have values of <1%. The requirement to pass the sodium sulphate resistance test according to SNI 03-0691-1996 is a paving block weight reduction of no more than 1%.

4. Conclusion
The CaO and SiO$_2$ content values in landfill mining residue were 5.81% and 46.31%, while values of CaO and SiO$_2$ content in glass waste were 8.77% and 65.07%. Paving block composition variations 2, 3, and 5 have met the SNI 03-0691-1996 classification of quality D used for city park use. The paving block composition variation 4 has also fulfilled SNI 03-0691-1996 with the classification of quality C for use as pedestrian walkway. The best values in the variation of the selected composition as the basic ingredients of making paving block based on SNI 03-0691-1996 on Paving Block are a compressive strength value of 18.84 MPa, water absorption value 3.41%, wear resistance value of 0.188 mm/min, and a sodium sulfate resistance rate of <1%.

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