The Influence of Aluminum Slag Ash for Paving Block Production

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Abstract. Aluminum slag ash commonly used as road and river embankments. It had disposed in an open site and potentially increase ammonia, sodium, potassium, chloride and total dissolved solids levels in the surrounding environment. As much as 90% of Portland cement is composed of a mixture of elements of Ca, Si, Al, and Fe which are bonded into certain complex compounds. This study aims to analyze the influence of cement substitution with aluminum slag ash on the compressive strength and water absorption capacity of the paving block, and the appropriate type of paving block quality which is following SNI 03-0691-1996. The test objects used were paving blocks with a ratio of cement and sand of 1:3, where the composition of the addition of aluminum slag ash was 5%; 10%; 15%; and 20%. The tests in this study were on compressive strength, water absorption capacity, and Toxicity Characteristic Leaching Procedure (TCLP) tests. The optimum composition is 10% aluminum slag ash in cement substitution. The type of quality is category B paving for parking equipment. The results of the TCLP on a 10% composition paving obtained that the parameter concentration is below the TCLP quality standard.

1. Introduction
The increasing the number of industries causes a lot of impacts which is linear with the increasing amount of industrial waste generation. It came from residual processes and materials that generate product from industrial production in factories or mining processes [1]. Ash from smelting industry residue is a material that contains aluminum. This material belong to hazardous waste which is toxic to the environment. Thousands of rice plastic bags are stacked in Jombang, East Java, to contain hundreds of tons of hazardous waste in the form of aluminum slag ash [2]. According to Government Regulation on the management of hazardous materials, aluminum slag ash is classified as hazardous waste from certain sources of primary and secondary production processes with code B313-2 [3]. When slag ash is submerged in water, it creates leachate that increases ammonia, sodium, potassium, chloride, and TDS levels in the environment [4].

Aluminum slag (asalum) consists of a coarse fraction with high metal content and a fine dust fraction containing metal oxides and salts [4]. Generally, aluminum slag waste still contains aluminum metal (10-20%), a mixture of salt flux (40-55%), and aluminum oxide (20-50%). The Salt flux mixture, known as salt cake, contains 5-7% aluminum residue, 15-30% aluminum oxide, 30-55% NaCl, and 15-30% KCl, as well as flakes containing carbidex, nitrates, phosphides, polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated-dibenzo-furan (PCDF). The metal content dominant in aluminum slag is 69.39% Aluminum Oxide, 8.31% Magnesium Oxide, 4.91% Silicate Oxide, 3.2% Calcium Oxide, 1.96% Iron Oxide and 1.9% Titanium Oxide [5]. Portland cement consists of a mixture of Ca, Si, Al, and Fe elements around 90% that combine to form certain complex compounds, so that aluminum slag ash has the potential to be a cement substitute material [6].

Concrete brick (paving block) is a choice for surface paving that has ease of installation and maintenance, is relatively inexpensive, and has an aesthetic aspect. Generally, paving blocks are used for pavement, pedestrian areas, and sidewalks. In addition, it can also be used in special areas such as...
container ports, parking lots, open spaces, and industrial areas. The advantage of paving blocks is that they have a good water absorption capacity. By installing paving blocks, the balance of groundwater can be maintained [7]. However, the high demand for paving blocks affects the rising prices and demand for the main raw materials used. To overcome this, good quality materials and alternative construction technologies that can reduce dependence on certain materials are needed [8]. Sustainable solid waste management is important in reducing the environmental pollution generated in an area. The pattern of reusing or recycling aluminum slag ash is expected to reduce the level of air, water, and soil pollution. Moreover, the development of this innovation will be able to reduce the production costs of building materials, considering that the materials used are waste or waste that is no longer used.

2. Materials and methods

Stabilization/solidification (S/S) is a process that involves mixing waste with a binder to reduce the leaching of contaminants both physically and chemically. S/S process converts hazardous waste into a form of waste that is acceptable to the environment to be disposed in the landfill or used for construction purposes [9]. This research using aluminum slag ash as a mix of ingredients to produced paving blocks due to environmental friendly which is follow SNI 03-0691-1996. Besides, Aluminum waste treatment is about synthetic zeolite that can be found on Aluminum Floride production with low temperature then added with concrete mix around 10%, it can be utilized as Portland cement substitution [10].

The main materials that are used are sand, cement, water, and Aluminum Slag Ash which is mixed with various compositions to identify the optimum composition for paving blocks. There were several stages of the research, starting from the preparation of materials to the results and conclusions that can be drawn. The stages of the research are carried out according to Figure 1.

![Figure 1 Stages of research](image)

2.1 Material Composition

Paving blocks use a mixture of cement and sand in a ratio of 1:3. The mixed material used in the manufacture of this paving block is aluminum slag ash from the refining process taken from the aluminum smelting home industry in Kendalsari Village, Sumobito District, Jombang Regency. This location was operated as smelting metal industry and there were a thousand kilos of aluminum slag ash unprocessed furthermore.

The composition sample consists of 5%; 10%; 15% and 20% Aluminum slag ash which is a substitution with the volume of cement used. For the production of a paving block with size of 20 cm x 10 cm x 6 cm, the material requirement must be calculated. The sand that used in this study has a specific gravity of 2.427 grams/cm3 according to the study of [11]. The cement used is Portland cement type 1 with a specific gravity of 3.15 g/cm³. The aluminum slag ash used has the properties listed in
Thus, the material required for paving can be calculated as follows in Table 2. Up to 16 pavers per composition were produced, resulting in a total of 80 paving blocks. The details can be seen in Table 3.

Table 1. Physical properties of aluminum slag ash

| No | Content                               | Percentage |
|----|---------------------------------------|------------|
| 1  | Specific Gravity (Bulk)               | 1.96       |
| 2  | Specific Gravity (SSD)                | 2.02       |
| 3  | Density (Pseudo)                      | 2.08       |
| 4  | Water Absorption Capacity             | 2.93%      |
| 5  | Material Passing Sieve No. 80         | 41.0%      |
| 6  | Material Passing Sieve No. 100        | 30.4%      |
| 7  | Material Passing Sieve No. 200        | 28.6%      |

Table 2. Paving block mix composition

| Composition | Cement (cm³) | Cement (gram) | Sand (cm³) | Sand (gram) | Aluminum Slag Ash (cm³) | Aluminum Slag Ash (gram) |
|-------------|--------------|---------------|------------|-------------|-------------------------|--------------------------|
| 0%          | 300          | 945           | 900        | 2184.3      | 0                       | 0                        |
| 5%          | 285          | 897.75        | 900        | 2184.3      | 15                      | 30.3                     |
| 10%         | 270          | 850.5         | 900        | 2184.3      | 30                      | 60.6                     |
| 15%         | 255          | 803.25        | 900        | 2184.3      | 45                      | 90.9                     |
| 20%         | 240          | 756           | 900        | 2184.3      | 60                      | 121.2                    |

Table 3. Details of the need for paving blocks

| Composition | Number of specimens for compressive strength | Number of specimens for water absorption capacity | Number of specimens TCLP | Total Specimen |
|-------------|---------------------------------------------|--------------------------------------------------|--------------------------|----------------|
| 0%          | 10                                          | 5                                                | 1                        | 16             |
| 5%          | 10                                          | 5                                                | 1                        | 16             |
| 10%         | 10                                          | 5                                                | 1                        | 16             |
| 15%         | 10                                          | 5                                                | 1                        | 16             |
| 20%         | 10                                          | 5                                                | 1                        | 16             |
| TOTAL       |                                             |                                                  |                          | 80             |

2.2 Testing Procedure

2.2.1 Compressive Strength

The procedure for testing the compressive strength is described below [12]:

a. The test sample is taken from 10 pieces which already have the shape of a cube.

b. The test sample is crushed with a pressing machine.

c. Compressive strength is calculated according to the formula:

\[
\text{Strength Compressive} = \frac{P}{L}
\]

Where:

P = Compressive Load (N)
L = Area of the Compression (mm²)
The average compressive strength is obtained by dividing the total compressive strength by the number of test samples.

2.2.2 Water Absorption Capacity
The procedure for testing the water absorption capacity is described below [12]:

a. Five test objects are soaked for 24 hours and then weighed in the wet state.

b. Drying of the test object in a drying cabinet (oven) for about 24 hours at a temperature lower than 105°C.

c. Weighing the paving that has been in the oven for 24 hours.

d. The water absorption capacity is calculated according to the formula:

\[
\text{Water Absorption Capacity} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100\% \tag{2}
\]

2.2.3 Toxicity Characteristic Leaching Procedure (TCLP)
TCLP is a laboratory procedure for predicting the potential leaching of toxic and hazardous wastes from a waste [3]. TCLP test is generally performed to identify the potential heavy metal toxicity. In this study, the final content test was conducted to determine the heavy metal content in the concrete block (paving block) which is aluminum slag ash had been added as cement substitution, and to determine whether or not safe for the environment according to TCLP standards.

TCLP with the characteristics of a non-volatile or semi-volatile solid-phase begins with the filtration of the sample with a dry solids content greater than 0.5% [13]. The solid-phase was then extracted with a weak acid at a specified pH using a suitable agitator rotating upside down at a rotational speed of 30 rpm ± 2 rpm for 18 hours ± 2 hours. Furthermore, the extract is combined with the liquid phase while the sample with a dry solids content of less than 0.5% is directly filtered with a 0.6 m - 0.8 m glass fiber filter and the filtrate is considered as a TCLP extract. The TCLP filtrate test methods can be seen in Table 4.
Table 4 TCLP filtrate test method

| Parameter      | Test Method                              | Test Standard         |
|----------------|------------------------------------------|-----------------------|
| Cl- (Chloride) | Argentometric Titration [14]             | SNI 06-6989-2009      |
| Pb (Lead)      | Atomic Absorption Spectrophotometry [14] | SNI 06-6989-2009      |
| Cu (Copper)    | Atomic Absorption Spectrophotometry [14] | SNI 06-6989-2009      |
| Zn (Zinc)      | Atomic Absorption Spectrophotometry [14] | SNI 06-6989-2009      |
| Cd (Cadmium)   | Atomic Absorption Spectrophotometry [14] | SNI 06-6989-2009      |
| Ag (Silver)    | Atomic Absorption Spectrophotometry [14] | SNI 06-6989-2009      |
| NO₂-N (Nitrite)| Spectrophotometry [15]                  | SNI 06-6989.9-2004    |

3. Results and Discussion

3.1 Compressive Strength Test

The compressive strength test of paving blocks carries out when the paving block had reached the age of 28 days in the dry state, using 10 specimens for each composition and taking the test results from the average number of specimens. The results of the compressive strength test can be seen in Figure 2.

Based on the results of the compressive strength test, which can be seen in Figure 2, it can be seen that the addition of aluminum slag ash as a cement substitute in paving blocks can decrease the compressive strength of paving blocks. This decrease is due to several factors. The first factor is the properties of aluminum slag waste, which has a low silica content. This prevents the occurrence of pozzolanic reactions with calcium silicate hydrate, commonly referred to as CSH. The second factor is the waste phase of aluminum slag in the form of aluminum crystals and a few silica crystals that do not easily react with the calcium in the cement. This makes the concrete surface hollow and decreases the specific gravity of the concrete [6]. Another factor that influences those condition is the Aluminum slag ash characteristic that has low silica, so that can be an inhibitor to pozzolanic reaction of calcium silicate hydrate (CSH) [16].

Another factor is the size of the aggregate. This affects the value of compressive strength, which goes up and down. One way to increase the compressive strength of concrete is to make extra-solid concrete using good aggregate gradation [17]. When the aggregate has a finer grain size and different sizes, the pore volume of concrete becomes smaller. It can be concluded that different aggregates can fill each other up, making the paving blocks denser [18]. Besides, comparison of water to cement could affect the comparative strengths test of concrete [19].
3.2 Water Absorption Test

The water absorption test of the paving blocks was carried out when the paving blocks had reached an age of 28 days in the dry state, using 5 specimens for each composition and taking the test results from the average number of test objects. It was necessary to identify the capacity of paving blocks containing water. The data result can be seen in Figure 3.

![Figure 3](image)

**Figure 3** The results of testing the water absorption capacity of paving blocks

Based on the results shown in Figure 3, the addition of aluminum slag ash for cement substitution on paving blocks tends to increase the water absorption value of the pavement, except for the percentage of addition of 10% aluminum slag ash composition, which decreased. The value of water absorption produced depends on the density and the number of voids contained in the paving block [20]. In this study, the sand material used was sand from Mount Merapi which has a size range of 0.15 mm - 4.8 mm [21]. The amount of mixture given for each mold on the machine or manual pressure device does not go through a weighing process first, so the amount is not the same [22]. As a result, the density of the sample different voids that are created will also vary.

Water absorption of concrete is naturally related to the nature of the pore system in the concrete itself [23]. Aggregates may also have pores, but these are usually intermittent. Concrete is at its best when absorption is less than 10%. Compared to this study, the absorption value obtained is still below 10% for each composition of the addition of aluminum slag ash.

3.3 Mixed Optimum Level

The optimum level of the mix is determined by the quality of the paving blocks. The determination of the quality of this paving blocks is based on the results of the compressive strength and water absorption tests carried out, which were compared with the quality of paving blocks [12]. The results of the comparison can be seen in Table 5.

| Ash Composition of Aluminum Slag | Average Compressive Strength (Mpa) | Quality of paving blocks based on compressive strength | Average water absorption (%) | Quality of paving blocks based on water absorption |
|---------------------------------|-----------------------------------|-----------------------------------------------------|-----------------------------|-----------------------------------------------|
| 0%                              | 43.21                             | A                                                   | 6                           | B                                             |
| 5%                              | 39.23                             | A                                                   | 7                           | C                                             |
| 10%                             | 33.65                             | B                                                   | 5                           | B                                             |
| 15%                             | 32.20                             | B                                                   | 8                           | C                                             |
| 20%                             | 17.43                             | B                                                   | 10                          | D                                             |
Based on Table 5, the quality of paving blocks is obtained from the results of various compressive strength and water absorption tests. The optimum level of the mix is determined for pavers that have the same quality results for compressive strength and water absorption. In this study, it is known that the optimum level is a mix composition of 10% with a compressive strength of 33.65 Mpa and a water absorption capacity of 5%, which is included in the category B paving quality that can be used for parking facilities.

3.4 TCLP Test
The TCLP test was conducted using pure aluminum slag ash and paving blocks with an optimum concentration of a 10% mixture of cement-substituted aluminum slag ash. This test was conducted to determine the potential of hazardous wastes leachate in paving blocks products with optimum composition. Based on Table 6, the hazardous and toxic waste parameter Pb in unprocessed aluminum slag has a value above the quality standard and has a value higher than the TCLP A quality standard, so this waste can be designated as a Category 1 waste. The waste is disposed of directly by the surrounding community. This aluminum slag will certainly have an acute and direct impact on humans later on and can certainly have a negative impact on the environment [3].

The appendix XII of Government Regulation number 22 of 2021 on quality standards for hazardous waste before disposal in a final landfill has the same value as the quality standard TCLP B [3]. Based on Table 6, it was found that the value of hazardous and toxic waste decreased after processing or stabilization on aluminum slag waste. Stabilization is a technique that reduces harmful pollutants in the waste by changing contaminants [24]. This involves reducing solubility, movement, and toxins. Solidification is a technique used to encapsulate waste into a solid form without requiring chemical interactions between contaminants and additive solidification agents. Stabilization solidification is a process that immobilizes metal elements, thereby reducing the potential of the elements polluting the environment [25]. The stabilization process in this study is the use of aluminum slag as a substitute for cement and the consolidation process in this study is the production of paving blocks. When compared with the results of the TCLP test on paving blocks with a composition of 10% on cement substitute, the parameter value is below the quality standard and is safe when used in the environment.

4. Conclusion
On the basis of this study, several conclusions can be drawn, such as:

- The substitution of cement with aluminum slag ash has a significant effect on the value of compressive strength and water absorption. The results of the compressive strength test decreased with the addition of aluminum slag ash, at 0%, 5%, 10%, 15%, and 20% substitution to 43.21 MPa, 39.23 MPa, 33.65 MPa, 28.2 MPa and 17.43 MPa respectively. The value of compressive strength is inversely proportional to the value of water absorption, the value of water absorption tends to
increase with the addition of aluminum slag ash, at 0%; 5%; 10%; 15%, and 20% substitution by 6%; 7%; 5%; 8%; and 10% respectively.

- The optimum composition is 10% aluminum slag in cement substitution. The type of grade is category B paving, which is paving used for parking equipment.
- The results of the TCLP investigation of paving with a composition of 10% gave a concentration of hazardous and toxic waste: Cl\textsuperscript- of 17.016 ppm; Pb of 0.4 ppm; Cu of 0.056 ppm; Zn of 0.579 ppm; Cd of 0.059 ppm; Ag of 0.004 ppm; NO\textsubscript{2} of 5 ppm and Cr\textsuperscript{6+} of 0.01 ppm. All parameters are below the established TCLP quality standard.

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