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# Utilization of Industrial Waste (Bottom Ash) as an Alternative Material in Paving Block Manufacturing

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ABSTRACT

The combustion process of coal in coal-fired power plants generates waste in the form of bottom ash residue. If not properly utilized, bottom ash has The ability to trigger adverse environmental impacts. One alternative for its utilization is as a mixture component in the production of paving blocks. This study aims to evaluate the water absorption, compressive strength, and quality classification of paving blocks incorporating bottom ash. An experimental laboratory method was employed by producing five different paving block variations with varying bottom ash percentages. The samples were then tested for compressive strength and water absorption in accordance with the Indonesian National Standard (SNI 03-0691-1996) to assess their conformity with established quality criteria.The paving block mixtures consisted of five variations: Sample A (0% bottom ash), Sample B (10%), Sample C (20%), Sample D (30%), and Sample E (40%), with each containing 30% cement and the remainder a combination of sand and bottom ash. The test results showed variations in average water absorption and compressive strength among the samples. Sample A had a water absorption of 8.95% and compressive strength of 15.1 MPa; Sample B, 5.99% and 22.73 MPa; Sample C, 6.54% and 22.49 MPa; Sample D, 8.34% and 19.49 MPa; and Sample E, 9.22% and 17.69 MPa. Based on the test results, paving blocks without bottom ash (Sample A) fall into Class C; mixtures with 10% and 20% bottom ash (Samples B and C) fall into Class B; the 30% mixture (Sample D) belongs to Class C; and the 40% mixture (Sample E) is categorized as Class D. All composition variations meet the quality classification criteria stipulated in the applicable Indonesian National Standard (SNI). Based on compressive strength and water absorption parameters, the optimal bottom ash composition ranges between 10% and 20%.

## 1. INTRODUCTION

Ketapang Regency is one of the largest administrative regions in West Kalimantan Province and possesses significant potential in the energy sector, particularly coal-based energy. Currently, two Coal-Fired Power Plant units are in operation within the region, utilizing coal as their primary energy source. As the demand for electricity continues to rise, the volume of coal combustion also increases, directly contributing to a substantial generation of waste by-products.

The coal combustion process in Coal-Fired Power Plants produces two main types of waste: fly ash and bottom ash. Fly ash consists of fine particles carried by exhaust gases and captured through emission control devices, whereas Bottom ash is a coarse, sand-like residue that settles at the base of the combustion chamber (Pangestuti et al., 2024). Bottom ash has the ability to absorb more water compared to sand, while its gradation falls into the coarse sand category (Pangestuti et al., 2023). It is formed during the furnace combustion process and consists of coal ash, quartz sand, and eroded fragments of the

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furnace wall. Historically, both types of waste were classified as hazardous and toxic materials (B3 waste) (Karolina et al., 2018).

However, based on regulations in Indonesia, fly ash and bottom ash (FABA) from Coal-Fired Power Plant operations are no longer categorized as B3 waste, but as non-hazardous and non-toxic waste. Nevertheless, their management remains subject to applicable technical standards and environmental documentation (Pemerintah Republik Indonesia, 2021).

This regulatory change has expanded opportunities for the utilization of FABA, particularly in environmentally friendly construction sectors. Effective reuse of such waste is crucial for mitigating harmful environmental effects, including soil and water contamination and public health risks associated with unmanaged waste accumulation. One promising application is the incorporation of bottom ash as a partial material substitute in paving block production, due to its physical characteristics that closely resemble fine aggregates such as sand (Heriyanti et al., 2020).

Recents studies have demonstrated that the partial replacement of aggregate with bottom ash in paving block production can offer added value from both technical and environmental perspectives. For instance study found that a 10% substitution of bottom ash yielded optimal results, with compressive strength reductions remaining within acceptable limits, water absorption levels compliant with standards, and decreased surface abrasion of the paving blocks (Laila & Risdianto, 2018).

The possibility of utilizing bottom ash instead of fine aggregates in paving block production has been widely explored. It was reported that incorporating 20% bottom ash in the mixture resulted in Class C paving blocks with acceptable compressive strength (Syapawi, 2023). Another study found that the use of bottom ash derived from the incineration of municipal solid waste enhanced compressive strength; however, substitutions exceeding 50% led to reduced abrasion resistance (Krisdiansyah et al., 2024). In quality parameter testing indicated that the 10% treatment complied with Class B standards, while the 15% treatment met the criteria for Class D (Ismail & Maulida, 2024). Another research found that a combination of bottom ash with particle sizes passing through 10 mm and 5 mm sieves could produce compressive strengths exceeding 40 MPa (Antoni et al., 2017). Furthermore, it was observed that higher proportions of bottom ash reduced compressive strength and increased water absorption, although the results still conformed to Class B standards according to the Indonesian National Standard (Togubu et al., 2019). These findings underscore the importance of optimizing the substitution ratio to ensure paving block quality that meets regulatory requirements (Naganathan et al., 2015).

Considering that the production of concrete paving blocks relies on non-renewable resources, with sand availability decreasing due to stricter environmental regulations, and coal waste from power plants posing environmental issues, the utilization of waste materials becomes essential (Antoni et al., 2017). Furthermore, the impact of varying bottom ash compositions on the mechanical properties of paving blocks requires further investigation, particularly in terms of quality and classification according to Indonesian National Standards. Therefore, this study aims to evaluate the use of bottom ash as a component in paving block mixtures, focusing on compressive strength and water absorption tests. The results will be assessed against the quality standards outlined in SNI 03-0691-1996, providing valuable insights into the feasibility of bottom ash in light construction industries.

## 2. METHODS

This study commenced with the sieving of bottom ash and sand using mesh sizes 16 and 10 to obtain uniform particle sizes and to eliminate impurities that could interfere with the sample preparation process. Subsequently, the materials were weighed according to the predetermined mix proportions. The sand, bottom ash, cement, and water were then mixed until a homogeneous consistency was achieved, and the mixture was manually molded using a form measuring 20 cm × 10 cm × 8 cm (Thambas et al., 2024), with applied compaction to ensure material density. The molded specimens were air-dried for 2 days under ambient conditions, followed by immersion in water for 7 days to enhance strength development through optimal cement hydration (Fikroni et al., 2023).

According to SNI, paving blocks are classified based on their quality and intended application. As outlined in Table 1, the classification is determined by usage categories: paving blocks of Grade A are designated for roadways, Grade B for parking areas, Grade C for pedestrian pathways, and Grade D for garden or landscaping applications. Manually produced paving blocks typically fall into concrete quality Grades D or C, which are intended for non-structural uses such as gardens and other areas that are not subjected to heavy loads (Badan Standarisasi Nasional, 2021).

**Table 1.** Quality Classification of Paving Blocks based on SNI

| Quality | Compressive Strength (MPa) | | Abrasion Resistance (mm/minute) | | Maximum Average Water Absorption (%) |
|---|---|---|---|---|---|
| | Average | Maximum | Average | Maximum | |
| A | 40 | 35 | 0.009 | 0.103 | 3 |
| B | 20 | 17 | 0.130 | 0.149 | 6 |
| C | 15 | 12.5 | 0.160 | 01184 | 8 |
| D | 10 | 8.5 | 0.219 | 0.251 | 10 |

### Compressive Strength Test

This test is carried out to identify the point at which a paving block fails under compressive load. This test follows the SNI 03-0691-1996 and is performed using a compression testing machine (Badan Standarisasi Nasional, 2021).

$$f_c = \frac{P}{A}$$

Where:

$f_c$ = Compressive strength (MPa)

$P$ = Maximum load at failure (N)

$A$ = Cross sectional area of the specimen ($mm^2$)

This test is essential for assessing the structural performance of paving blocks, as compressive strength is a key indicator of their suitability for applications such as roadways, sidewalks, and parking areas.

**Water Absorption Test**

It is conducted to determine the water-absorbing characteristics of the paving block, which is directly related to its durability under weather exposure and traffic loads. A lower water absorption value indicates a denser, higher-quality paving block (Badan Standarisasi Nasional, 2021).

$$Water\ Absorption\ (\%) = \left(\frac{W_{wet} - W_{dry}}{W_{dry}}\right) \times 100\%$$

Where:

$W_{wet}$ = weight of the paving block after immersion (kg)

$W_{dry}$ = weight of the paving block after drying (kg)

This test is conducted by weighing the paving block in its dry state and again after being submerged in water for 24 hours, following the procedure specified in SNI 03-0691-1996.

## 3. RESULT AND DISCUSSION

This study aims to evaluate the use of bottom ash as a mixture component in the production of paving blocks. The research process began with sieving the bottom ash using mesh sizes 16 and 10 to obtain uniform particle sizes free from impurities. Next, the materials—bottom ash, sand, cement, and water—were weighed according to predetermined mixture proportions. The materials were then thoroughly mixed and manually molded into molds measuring 20 cm × 10 cm × 8 cm. The molded specimens were air-dried for 2 days under ambient conditions, followed by immersion in water for 7 days to enhance strength development through optimal cement hydration. After drying, physical tests were conducted, including compressive strength and water absorption tests, following the procedures outlined in SNI 03-0691-1996. The compressive strength test aimed to determine the maximum load the paving blocks could withstand before failure, while the water absorption test assessed density, moisture resistance, and classification of quality grades. The test data were analyzed to identify the optimal mixture composition that meets the quality standards for paving blocks classified as Class C or D.

The study involved the preparation of fifteen samples for experimental analysis. The mixture composition variations are presented in Table 2, consisting of five types of mixes: Sample A (0% bottom ash, 70% sand, 30% cement), Sample B (10% bottom ash, 60% sand, 30% cement), Sample C (20% bottom ash, 50% sand, 30% cement), Sample D (30% bottom ash, 40% sand, 30% cement), and Sample E (40% bottom ash, 30% sand, 30% cement). Each mixture variation was replicated in three samples.

**Table 2.** Mixture Composition of Paving Blocks

| Sampel Code | Composition Variation (%) | | |
|---|---|---|---|
| | Battom Ash | Sand | Cement |
| A | 0 | 70 | 30 |
| B | 10 | 60 | 30 |
| C | 20 | 50 | 30 |
| D | 30 | 40 | 30 |
| E | 40 | 30 | 30 |

**1. Visual Characteristics**

The visual characteristics of paving blocks must conform to the standard requirements for uniform shape, free from cracks or defects at the corners and surfaces. This assessment was conducted on all 15 samples, labeled A1 to E3, through direct visual observation. The results indicated that none of the samples exhibited visible cracks or physical defects. Therefore, all paving blocks were deemed to meet the specified visual quality standards.

**2. Dimensions**

According to SNI 03-0691-1996, paving blocks must have a minimum nominal thickness of 60 mm, with an allowable tolerance of ±8%. The measurement results of all samples indicate that their thickness falls within the permissible tolerance range, specifically at 80 mm. Therefore, all samples comply with the dimensional requirements specified in the standard.

**Figure 1.** Sample of Paving Blocks

**3. Water Absorption Test**

The objective of the water absorption test is to measure the paving blocks' density, hardness, and specific gravity. High-quality paving blocks are characterized by low water absorption and high compressive strength. Based on SNI the standard range for water absorption is 3%–10% (Badan Standarisasi Nasional, 2021).

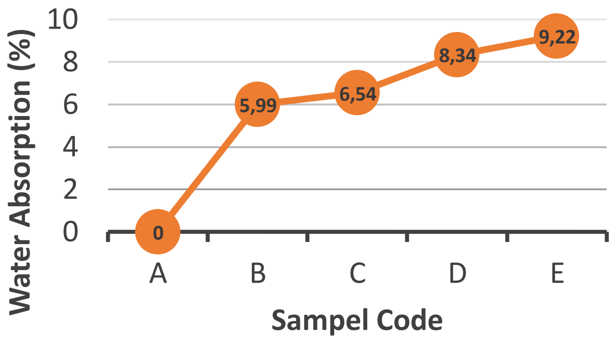


**Figure 2.** Average Water Absorption of Paving Blocks

The test results indicated that the average water absorption values varied as follows: Sample A recorded 8.95%, Sample B 5.99%, Sample C 6.54%, Sample D 8.34%, and Sample E 9.22%. The addition of bottom ash influenced the water absorption values, where higher percentages resulted in increased water absorption due to the rising porosity of the material. The most optimal water absorption values were observed at bottom ash compositions of 10% and 20%. These findings are in line with the results of (Siddique, 2013), which showed that higher porosity from ash content leads to increased water absorption.

**4. Compressive Strength Test**

The compressive strength test aims to determine the paving block's ability to withstand load. The results indicated that the average compressive strength for Sample

A was 15.1 MPa, Sample B was 22.73 MPa, Sample C was 22.49 MPa, Sample D was 19.49 MPa, and Sample E was 17.69 MPa. These results show that the addition of bottom ash up to 20% enhanced compressive strength; however, further increases in bottom ash content led to a decrease in strength.

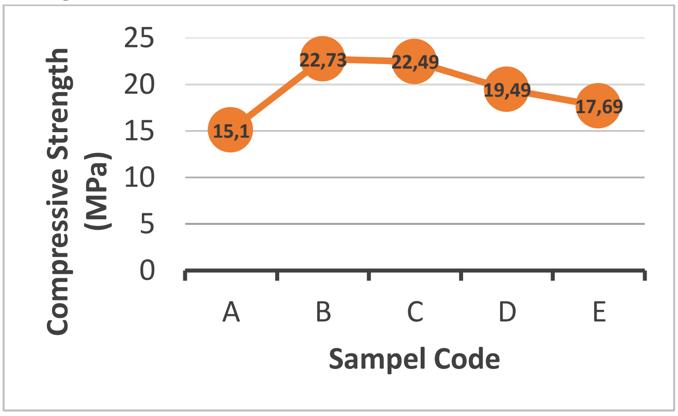


**Figure 3.** Average Compressive Strength of Paving Blocks

As illustrated in Figure 3, an increase in the proportion of bottom ash in the mixture leads to a reduction in the compressive strength of the paving blocks. This decline is attributed to the excessive addition of bottom ash, which lowers the bulk density and compactness of the material, thereby affecting its load-bearing capacity. Based on the compressive strength test results, Sample A falls under Quality Class C, which is suitable for pedestrian walkways. In contrast, Samples B, C, D, and E are classified under Quality Class B, making them appropriate for light vehicle parking areas. Although, in general, the addition of bottom ash tends to reduce compressive strength, mixtures containing 10% and 20% bottom ash exhibited the highest compressive strength values among all variations. These findings are consistent with the results reported by (Al Biajawi et al., 2023) which showed that the highest compressive strength was achieved with a 10% bottom ash mixture. This indicates that at certain levels, bottom ash can still contribute positively to the mechanical performance of paving blocks. Similar trends were observed in the study by (Antoni et al., 2017), where paving blocks incorporating 5 mm bottom ash showed superior compressive strength compared to finer ash. Likewise, (Singh & Bhawsar, 2020) reported that fly ash substitution up to 30% can enhance compressive strength when used in combination with other additives.

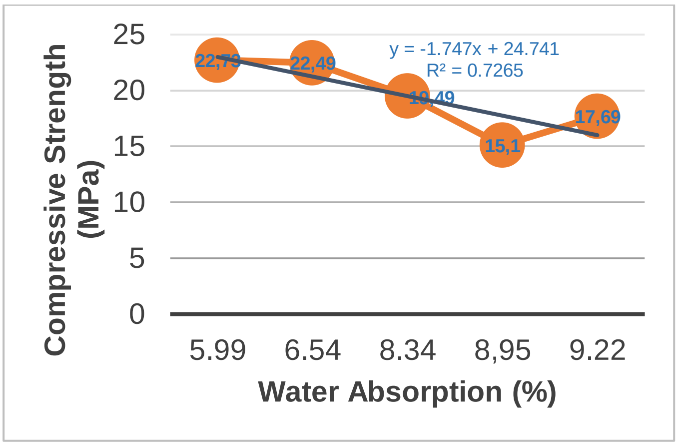


**Figure 4.** The Correlation Curve Between Water Absorption and Compressive Strength

Research has shown that the Utilization of bottom ash as a partial replacement for fine aggregate in the production of paving blocks significantly affects the mechanical and physical properties of the material. In general, increasing the proportion of bottom ash tends to raise water absorption and reduce compressive strength. This is due to the porous nature of bottom ash compared to natural sand, which increases the total porosity of the mixture and allows more water to be absorbed. Consequently, the higher porosity weakens the interparticle bonding and decreases the mechanical strength of the paving blocks.

This is consistent with the study conducted by (Singh & Bhawsar, 2020), which reported that substituting bottom ash for fine aggregate led to increased water absorption and a corresponding decrease in compressive strength. In addition, research by (Fazli, 2021) indicated that using bottom ash with a larger particle size (5 mm) resulted in lower water absorption compared to smaller particle sizes (2 mm), while still meeting standard specifications for abrasion resistance.

Therefore, it is crucial to determine the optimal proportion and particle size of bottom ash in the paving block mixture to achieve a balance between water absorption and compressive strength that complies with technical requirements and quality standards.

## 5. Paving Block Quality Classification

The quality classification of paving blocks is intended to evaluate the compressive strength and water absorption in accordance with the application standards specified in SNI 03-0691-1996.

**Table 3.** Paving Block Quality Classification Based on Water Absorption and Compressive Strength

| Sampel Code | Average Water Absorption (%) | Average Compressive Strength (MPa) | Quality Classification |
|---|---|---|---|
| A | 8,95 | 15.10 | C |
| B | 5.99 | 22.73 | B |
| C | 6.54 | 22.49 | B |
| D | 8.34 | 19.49 | C |
| E | 9.22 | 17.69 | D |

Based on the quality classification above, it can be observed that Sample A, which contains no bottom ash, falls into Class C based on its compressive strength and water absorption results, indicating suitability for pedestrian areas. Sample B, with 10% bottom ash, and Sample C, with 20% bottom ash, both fall into Class B, making them appropriate for parking areas. Sample D, incorporating 30% bottom ash, is classified as Class C and suitable for use in garden areas. Sample E, with 40% bottom ash, is categorized under Class D, which is applicable for gardens and other low-load applications. These findings indicate that the best performance in aspects of compressive strength and water absorption was achieved with bottom ash content of 10% and 20%, which aligns with the results of (Nur Ihfansyah & Teguh, 2024) and (Singh & Bhawsar, 2020), who also reported ideal mechanical behavior at moderate substitution levels.

## 4. CONCLUSION

The variation in bottom ash content significantly affects the water absorption value. Each increase in bottom ash proportion leads to a higher percentage of water absorption due to the increased porosity of the mixture, which facilitates water penetration into the paving blocks. Higher bottom ash content tends to reduce the paving block's compressive strength. This is due to the decrease in bulk density and compactness of the material, which adversely affects its ability to withstand compressive loads. The optimal results for both compressive strength and water absorption were obtained from mixtures containing 10% and 20% bottom ash. These two compositions fall under Quality Class B, which is suitable for use in light vehicle parking areas.

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