The effect of partial granulated blast furnace slag (GBFS) substitution and ashes of the boiler crust of the palm oil shells on paving block

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Abstract. Paving block is a building material made of cement, water, and fine aggregate used as an alternative cover or hardening for land surface. It is commonly used for various purposes such as, sidewalks, parking lots, and road pavement. The increasing demand of cement-forming materials is due to the rise in the number of cement users, therefore, an environmentally friendly material is needed to be produced from industrial waste. Generally, Indonesia has extensive oil palm plantations, as a result, excess wastes are produced from the burning of oil palm shells namely, boiler scale ash (contains silica oxides (SiO₂), pozzolan, and other compounds present in cement). Smelting and metal refining industries produce wastes from Granulated Blast Furnace Slag (GBFS), which contains silica oxide as their major chemical composition. Therefore, this study aims to determine the compressive strength and the water absorbing capacity of paving blocks using 10% of Palm Boiler Crust Ash as a substitute for fine aggregate /sand, and the percentage variations of Granulated Blast Furnace Slag (GBFS) waste as a cement replacement material. The results showed that the paving block variation V₂ had the highest compressive strength (22.83 MPa), while the highest water absorption (5.45%) was found in variation V₁, which was higher than the normal paving block (2.39%).

1. Introduction
Currently, paving blocks have many uses which include, their utilization in parking plazas, hotels, recreation areas, historic sites, for terminals, footpaths, and pavement environments in residential complex. They are also called concrete or cone blocks and contains similar constituents present in cement[1]. The increasing demand of cement in the construction industry has led to the various attempts made in searching for raw material with the same chemical compounds present in cement[2]. One of which is the utilization of waste products from industries[3].

Generally, Indonesia has extensive oil palm plantations, as a result, excess wastes are produced from the burning of oil palm shell namely, boiler scale ash (contains silica (SiO₂), pozzolan, and other cement constituents)[4]. Smelting and metals refining industries produce wastes from Granulated Blast Furnace Slag (GBFS), which contains silica oxide as their major chemical composition[5].

Therefore, this study aims to determine the compressive strength and the water absorbing capacity of paving blocks using 10% Palm Boiler Crust Ash as a substitute for fine aggregate /sand, and the percentage variations of Granulated Blast Furnace Slag (GBFS) wastes as a cement replacement material.
1.1 The Problem to be addressed

The increasing search for cement's raw materials has led to the optimization of industrial wastes, especially those from Granulated Blast Furnace Slag (GBFS) and Palm Boiler Crust Ash (BCA). These wastes are tested for compressive strength in accordance with the SNI standard for normal paving blocks [6]. The percentage composition of the Granulated Blast Furnace Slag (GBFS) wastes used for cement replacement were, 0%, 25%, 50%, 75%, and 100%, while 10% of Palm Boiler Crust Ash (BCA) for fine aggregate /sand substitution. Therefore, the various percentage compositions of GBFS cement with 10% BCA fine aggregate /sand substitution on the paving block produced an optimum compressive strength.

Furthermore, the GBFS and BCA are environmentally friendly materials used for cement and sand substitution, due to their higher compressive strength and water absorbing capacity compared to the conventional paving blocks.

2. Methodology

The Granulated Blast Furnace Slag (GBFS) waste and the Palm Boiler Crust Ash (BCA) were proportionally mixed.

| Material          | 7 Days | 14 Days | 28 Days | Total   |
|-------------------|--------|---------|---------|---------|
| **Cement**        | 2.28 kg| 2.28 kg | 4.56 kg | 9.12 kg |
| **Sand**          | 4.80 kg| 4.80 kg | 9.60 kg | 19.20 kg|
| **Cement**        | 1.71 kg| 1.71 kg | 3.42 kg | 6.84 kg |
| **Sand**          | 4.20 kg| 4.20 kg | 8.40 kg | 16.80 kg|
| **GBFS**          | 0.63 kg| 0.63 kg | 1.26 kg | 2.52 kg |
| **BCA**           | 0.42 kg| 0.42 kg | 0.84 kg | 1.68 kg |
| **Cement**        | 1.14 kg| 1.14 kg | 2.28 kg | 4.56 kg |
| **Sand**          | 4.20 kg| 4.20 kg | 8.40 kg | 16.80 kg|
| **GBFS**          | 1.26 kg| 1.26 kg | 2.52 kg | 5.04 kg |
| **BCA**           | 0.42 kg| 0.42 kg | 0.84 kg | 1.68 kg |
| **Cement**        | 0.57 kg| 0.57 kg | 1.14 kg | 2.28 kg |
| **Sand**          | 4.20 kg| 4.20 kg | 8.40 kg | 16.80 kg|
| **GBFS**          | 1.89 kg| 1.89 kg | 3.78 kg | 7.56 kg |
| **BCA**           | 0.42 kg| 0.42 kg | 0.84 kg | 1.68 kg |
| **Cement**        | 0 kg    | 0 kg    | 0 kg    | 0 kg    |
| **Sand**          | 4.20 kg| 4.20 kg | 8.40 kg | 16.80 kg|
| **GBFS**          | 2.52 kg| 2.52 kg | 5.04 kg | 10.58 kg|
| **BCA**           | 0.42 kg| 0.42 kg | 0.84 kg | 1.68 kg |

2.1 Research Process

The issue reviewed in this study was determining the correlation value between the use of Granulated Blast Furnace Slag (GBFS) as a cement substitution with 10% of Palm Boiler Crust Ash (BCA) as a fine gradation /sand substitution in the manufacture of conventional paving blocks.

3. Laboratory Testing Result

3.1 Laboratory Testing Result

The fine aggregate used in the paving block mixture was examined for its parameters [7], which included the gradation and unit weight.
3.1.1 Test Result Analysis of Palm Boiler Crust Ash (BCA)

The results showed that Palm Boiler Crust Ash (BCA) belongs to the fine aggregate category (Zone III) with a fineness modulus of 2.158, which meet the requirements stipulated in ASTM C-33[8], namely the modulus refinement of 2.3 - 3.1. Therefore, confirming the use of Palm Boiler Crust Ash waste as a paving block mixture material.

3.1.2 Unit Weight of Palm Boiler Crust Ash (BCA).

The test result of unit weight of Palm Boiler Crust Ash amounted to 1448.16 kg/m³.

**Table 2.** Unit Weight of Palm Boiler Crust Ash (BCA).

| No | Description                          | Result | Unit   |
|----|--------------------------------------|--------|--------|
| 1  | Empty Vessel Weight (B₁)              | 5.88   | Kg     |
| 2  | Vessle Weight + BCA (B₂)              | 20.24  | Kg     |
| 3  | Sand Weight (B₃ = B₂ - B₁)            | 14.36  | Kg     |
| 4  | Volume of Steel Vessel (V)            | 0.009916 | m³   |
| 5  | Unit Weight of Sand (γ)               | 1448.16 | Kg/m³ |

\[ γ = \frac{B₃}{V} \]
3.1.3 Specific Gravity Analysis of Granulated Blast Furnace Slag (GBFS).

| No | Examination Test                          | Result | Unit |
|----|-------------------------------------------|--------|------|
| 1  | Weight of GBFS (A)                        | 75     | gr   |
| 2  | Volume of kerosene (B₁)                   | 0,8    | ml   |
| 3  | Volume of kerosene + GBFS (B₂)            | 22,20  | ml   |
| 4  | Specific Gravity of GBFS = \( \frac{A}{B₂−B₁} \) | 3,505  | gr/ml|

Table 3. Specific Gravity of Granulated Blast Furnace Slag (GBFS).

3.2 Paving Block Compressive Strength Result

![Compressive Strength of All Variations](image)

Figure 2. Paving Block Variation Value Testing Results.

Based on figure 2, the compressive strength of variation V2 (10% BCA with + 50% GBFS) had the highest value compared to the normal paving blocks. While the maximum compressive strength V₂ (10% BCA + 50% GBFS) at 28 days was 22.83 MPa, and higher than the normal variation V₀ (20.25 MPa).
3.3 Paving block Absorption Testing Results

Based on figure 3, the water absorption values of all variations were lower than those of normal paving blocks. The highest absorption value of 5.45% in V1 (10% BCA + 25% GBFS) was lower than the normal paving block V0 of 2.39%. Meanwhile, the value of water absorption was lower with the increasing use of GBFS, as a result, reduced cement use in order for the aggregate binding process of GBFS to occur optimally, which did not cause many pores/cavities in the paving block structure[9].

4. Conclusion

Based on the results of research and analysis, several conclusions were made such as, the highest compressive strength is found in the paving block variation V₂ (10% BCA + 50% GBFS) at 28 days (22.83 MPa), and higher than the normal variation V₀ (20.25 MPa). The water absorption values of all variations are lower than those of normal paving blocks. Therefore, the highest absorption value of 5.45% in V₁ (10% BCA + 25% GBFS) is found to be lower than the normal paving block V₀ of 2.39%.

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