Development of eco-friendly paving block incorporating co-burning palm oil processed tea waste ash

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Abstract. The present study explores the development of eco-friendly paving block incorporating co-burning palm oil processed tea waste ash (POPTA). POPTA was collected from the local tea processing plants and used to manufacture paving block at a local paving block industry with dosages ranging from 10 to 60% by cement weight. The properties of the paving block were investigated, including bulk density and compressive strength. Results show that the POPTA produced a lighter weight paving block. It also decreased the compressive strength of the paving block. Incorporating up to 40% of POPTA as cement replacement satisfied the minimum standard compressive strength requirements for the Class D paving block according to SNI-03-0691-1996. Utilization of POPTA in production paving block could mitigate the landfilling of this by-product and lead to the development of eco-friendly and economical construction materials.

1. Introduction

Paving blocks are used worldwide in streets, driveways, sidewalks and parking/garage. Paving blocks are mainly composed of cement, water, coarse and fine aggregates. Due to the increasing use of paving block in the construction industry, associated with the need for reducing the consumption of natural resource and production costs, researchers have focused on incorporating different solid waste/by-products as alternative materials in paving blocks. Most of the previous studies used waste material for aggregate replacement in paving block production such as recycled demolition aggregates, rubber waste, recycled CRT funnel glass and crushed ceramic [1-4]. However, little studies have found on the utilization of waste material as cement replacement in paving block production. For instance, Ganjian et al. The study used by-product and waste materials such as granulated blast furnace slag (GGBS), cement by-pass dust (BPD), run-of-station ash (ROSA), basic oxygen slag (BOS) and plasterboard gypsum (PG) as cement replacement. The test results confirmed that a concrete paving mix containing 6.3% GGBS, 0.7% BPD and 7.0% OPC by weight can decrease Portland cement content by 30% without having a substantial impact on strength and durability of the paving blocks [5]. The research studied the replacement of Portland cement with GGBS and silica fume (SF) in the paving block and found that cement content reduced by 40% by incorporating GGBS and SF [6]. The study investigated the mechanical and durability properties of concrete paving block incorporating cement kiln dust (CKD). Results indicated that up to 40% CKD could be used for producing environmental-friendly paving blocks for heavy traffic applications, while 60% CKD block is suitable for areas subjected to medium traffic applications such as in city streets. Incorporating
waste material as cement replacement in paving block production could contribute to the reduction of greenhouse emissions from cement production. Approximately 8% of global CO$_2$ emissions coming from the cement industry. Therefore, this study aims at investigating the possibility of palm oil-processed tea waste ash (POPTA) as a cement replacement in paving block production. POPTA was used as partial replacement of cement at 10, 20, 30, 40 and 60%. This application will not only help in solving the environmental problems generated from POPTA disposal but also will reduce the consumption of significant quantities of cement used in the paving block industry.

2. Materials

2.1. Cement
Portland Composite Cement (PPC) which conformed to SNI 15-7064-2004 with a specific gravity of 3.08 was used [7]. The PCC equivalent with CEM Type II/A-M cement contains 80% clinker and 20% mineral admixture, including ground granulated blast furnace slag, silica fume, fly ash and gypsum [8,9].

2.2. Aggregates
Natural river sand with a fineness modulus of 2.77 and a specific gravity of 2.58 was used as fine aggregate. The coarse aggregate was stone dust with a maximum size of 2.0 mm and a specific gravity of 2.83.

![Figure 1. Palm oil (70%) and processed tea (30%) waste.](image1)

![Figure 2. POPTA after sieved to 75 μm.](image2)
2.3. Palm Oil-Processed Tea Waste Ash (POPTA)

POPTA is a by-product obtained from small power plants of a tea processing plant in Gowa, Indonesia. POPTA was obtained by co-burning 70% palm oil and 30% processed tea waste as shown in figure 1 at a temperature from 700-800ºC to produce energy for extracting the process of tea leaf. The as-received POPTA consists of a coarser particle and a small amount of carbon particle. Then, POPTA was sieved passing through the No. 200 (75 µm) before use as cement replacement in paving block as shown in figure 2.

3. Specimens preparation and testing

Paving blocks were manufactured in a local factory in Makassar to study the feasibility of producing a paving block in real industrial production conditions. Paving blocks were designed for non-traffic applications such as sidewalks, garage, and indoor areas. POPTA was used to replace 10%, 20%, 30%, 40% and 60% of cement weight. Table 1 shows the mix proportion of paving blocks. The mixing procedure was as follows: First, cement/POPTA, fine and coarse aggregates were dry mixed manually. Afterward, water was added the mix and mixing was continued until the mixture is homogeneous. Finally, the fresh mix was filled in steel molds of 200 mm x 100 mm x 70 mm and compacted using a handy press. After that, the blocks were left in the open air for 24 h before cured by sprinkling water twice per day for 28 days. The schematic procedures of making paving block are depicted in figure 3.

Table 1. Mix proportion of paving block.

| No | Mix ID | Cement (%) | POPTA (%) |
|----|--------|------------|-----------|
| 1  | M1     | 100        | 0         |
| 2  | M2     | 90         | 10        |
| 3  | M3     | 80         | 20        |
| 4  | M4     | 70         | 30        |
| 5  | M5     | 60         | 40        |
| 6  | M6     | 40         | 60        |

Figure 3. Procedures of making paving block (a) mixing; (b) fresh blocks; (c) curing.

Figure 4. Compressive strength test.
Paving blocks were tested for density and compressive strength at 28 days. The specimens were dried in an oven at 105 ± 5°C for 24 h. Afterward, specimens were cooled in controlled room 20 ± 5°C for 6 h and their weight was recorded. Density was expressed as a ratio of the mass specimen to the volume of the specimen. Compressive strength was performed according to SNI-03-0691-1996 [10] using a 1000 kN universal testing machine as shown in figure 4. The load was applied normal to the bed area of the paving block. Compressive strength was determined by dividing the failure load by the loading area of the block.

4. Results and discussion

4.1. Characterization of POPTA

The physical and chemical compounds of POPTA used in this study are presented in table 2. POPTA has a specific gravity of 2.05. The chemical analysis showed that the POPTA had silicon oxide (SiO\textsubscript{2}), aluminum oxide (Al\textsubscript{2}O\textsubscript{3}) and iron oxide (Fe\textsubscript{2}O\textsubscript{3}) values of 63.70, 3.87 and 2.14%, respectively. The sum of percentage masses of the three oxides was 69.65%, which was closed to 70% limit specified for pozzolan Class F by ASTM C618-78 [11]. The scanning electron micrograph (SEM) of POPTA is given in figure 5. It can be seen from the figure the POPTA particles are mainly of an irregular shape with a porous surface structure.

| Properties               | Value  |
|--------------------------|--------|
| Specific gravity         | 2.05   |
| A chemical compound (%)  |        |
| SiO\textsubscript{2}     | 63.70  |
| Al\textsubscript{2}O\textsubscript{3} | 3.87   |
| Fe\textsubscript{2}O\textsubscript{3} | 2.41   |
| CaO                      | 16.31  |
| SO\textsubscript{3}      | 0.32   |
| MgO                      | 0.11   |
| K\textsubscript{2}O      | 4.13   |
| LOI                      | 10.74  |
| SiO\textsubscript{2} + Al\textsubscript{2}O\textsubscript{3} + Fe\textsubscript{2}O\textsubscript{3} | 69.65 |

Figure 5. SEM image of POPTA.
4.2. Density

Figure 6 shows the density of the paving block with a variation of POPTA replacement. The densities of the paving block are decreased with an increase in POPTA replacement. The density of paving block without POPTA (M1) was 2019.5 kg/m³ and decreased by 1.55, 3.56, 4.67, 6.75 and 11.81% with replacement 10, 20, 30, 40 and 60% of POPTA. This is due to low-density POPTA partially replaced with a high density of cement.

![Figure 6. The density of the paving block.](image)

4.3. Compressive strength

The compressive strength value of the paving block with different POPTA content is presented in Figure 7. It can be seen from Figure 7, a higher compressive strength achieved in 10% of POPTA replacement (M2) and an increase in the POPTA replacement over 10% steadily decreased the strength of the paving block. The reason for compressive strength improvement due to the silica contained in POPTA react with calcium hydroxide (C-H) and convert to high strength calcium silicates hydrates (C-S-H). For higher replacement POPTA (20 – 60%), due to an excessive amount of silica in the mix and reduction in cement content, there is no enough C-H to react with silica and C-S-H gel formation was limited. Therefore, it resulted in a deficiency in strength [12].

![Figure 7. Compressive strength of the paving block.](image)

Although, a reduction in compressive strength was observed with incorporating of POPTA in paving block; however, it still satisfied the minimum compressive strength of paving block according to Indonesian standard up to 40% replacement of POPTA. Table 3 shows the classification of the
paving block contained POPTA according to SNI 03-0691-1996. From table 3, a 10% replacement of POPTA is categorized as Grade B for application of parking area/garage. While for 20 – 40% replacement of POPTA classified into Grade C and used for garden and sidewalks.

| Mix | POPTA replacement (%) | Compressive strength (MPa) | Classification | Min. Compressive strength (SNI) (MPa) |
|-----|------------------------|-----------------------------|----------------|-------------------------------------|
| M1  | 0                      | 17.2                        | Grade B        | 17.0                                |
| M2  | 10                     | 19.8                        | Grade B        | 17.0                                |
| M3  | 20                     | 13.4                        | Grade C        | 12.5                                |
| M4  | 30                     | 11.9                        | Grade C        | 12.5                                |
| M5  | 40                     | 10.3                        | Grade C        | 12.5                                |
| M6  | 60                     | 6.8                         | Not Classified | 8.5                                 |

5. Conclusions

- POPTA allowed the production of lighter weight paving blocks.
- The compressive strength was increased 15.11% for paving block incorporating 10% of POPTA.
- Although adding POPTA in paving block reduced the block compressive strength, block incorporating up to 40% POPTA satisfied the minimum compressive strength requirements of Grade C for garden and sidewalks application according to SNI 03-0691-1996.
- Utilization of POPTA in production paving block could mitigate the landfilling of this by-product and lead to the development of eco-friendly and economical construction materials.

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