Abstract

Utilization of bottom ash, which is a by-product of coal combustion, will be an appropriate solution for the arising environmental problems as well as the scarcity of raw materials. In the future utilization of bottom ash will be a necessity than a desire as the generation of bottom ash will be in large quantity. Although bottom ash has the properties which suits for constructions, still bottom ash is considered as a waste material and is being dumped to the lands in large quantities.

Concrete paving blocks, which have multiple advantages such as fast in assembling, excellent drainage capacity, easy handling and fast production, are increasingly used in Sri Lanka. Objective of this study is to utilize bottom ash in production of paving blocks.

Paving blocks were manufactured using bottom ash in varying replacement level (0%, 10%, and 20% by weight) of fine aggregates (i.e., sands), in order to determine the optimum replacement level. Physical properties (i.e., density and particle size distribution) of the bottom ash were investigated. In addition, compressive strength, water absorption and workability of the developed blocks were investigated. It has been found that bottom ash can effectively be utilized in the manufacturing of paving blocks.

Keywords: Bottom ash, Paving blocks, Compressive strength, Water absorption, Workability

1.0 Introduction

Bottom ash, which is one of the by – product of coal combustion other than fly ash, has been an available material in Sri Lanka, since currently Sri Lanka meets its power requirement from coal power –based power plants. It can be expected that a large quantity of bottom ash will be available in the future. According to the Ceylon Electricity Board (CEB) Generation Performance in Sri Lanka 2012, electricity generation based on coal power plant had been increased by 8.25% within a one year. In addition CEB has predicted that, in year 2021, the major share of the new capacity of power
generation (i.e. 84%) will be from coal-based power plants. Bottom ash can have various applications including usage as a soil stabilizer, fill material and material in constructing noise barriers.

Although fly ash is being utilized as a raw material for the cement and concrete industry, utilization of bottom ash hasn’t been considered in Sri Lanka; and is being dumped to lands as a waste material. In Sri Lanka, there is no proper system either to dispose or utilize bottom ash. Therefore, disposal of bottom ash will cause severe environmental problems in the future. Meanwhile, bottom ash may have the appreciable properties so that bottom ash can be used as a construction material. Therefore utilization of bottom ash as a construction material will be an appropriate solution for the environmental problem that may arise.

Apart from that, currently there is a scarcity of natural resources, especially fine aggregates. Also sand is available from sand mining which is also not an environmental friendly activity. Since physical properties, physical appearance and geometry of bottom ash are similar to fine aggregate; (i.e., sand), bottom ash can be used as a replacing material or as an alternative for sand (Mohd et al, 2011).

Bottom ash is used as a construction material in several applications, such as concrete, self-compacting concrete, masonry blocks and pavement blocks. Although bottom ash can be utilized as a replacement, there are some application limitations that should be taken into consideration; as bottom ash is a waste material, occasionally utilization of bottom ash in construction applications such as self-compacting concrete will not have a tendency. However there is a tendency in utilizing bottom ash in pavement blocks, which have multiple advantages such as fast in assembling, excellent drainage capacity, easy handling and fast production.

Objective of the current study is to investigate structural properties of pavement blocks manufactured with bottom ash, since structural performance should be at an appropriate range. As pavement blocks are subjected to certain loads, it is necessary to investigate the effect use of bottom ash on structural performance of pavement blocks when bottom ash is being used.

2.0 Methodology

2.1. Selection of Material

Bottom ash was collected from the Norachcholai coal power plant. River sand, Ordinary Portland Cement and clean water were used in manufacturing the paving blocks.

2.2 Manufacturing of Paving Blocks

A paving block having a size of 200 mm x 100 mm x 70mm (Figure 1) was cast with the mix proportion of 1:2:4: cement: sand: chips as suggested by Baskaran and Gopinath, (2011) and bottom ash was used as a replacement for sand in various percentages.

Plastic moulds were used for casting of paving blocks (Figure 2). Before pouring the mixture to the moulds, mould oil was applied in the moulds, so as to make it easy to remove the blocks from the mould.

As the 10% and 20% replacement level had been found as the optimum replacement level for concrete (Kasemchaisiri and Tangtermsirikul, 2008) and for masonry (Abeykoon et al, 2012), 0%, 10%, and 20% replacement levels were selected in this study. Effects of replacement levels of bottom ash on compressive strength, water absorption and workability were determined.
In order to cast paving blocks, cement, sand and bottom ash were measured and mixed thoroughly. Chips and water were mixed and again the mixture was turned over number of times so that it is mixed well. The moulds were filled with the mixture in 2 layers; one third of the total height as the first layer and two third of the total height as the second layer and each layer was compacted using the vibration table for about 5 minutes. The moulds with mixture were kept for 24 hours and the blocks were removed from the moulds. For the purpose of curing the blocks were kept in the curing tank until the day of testing.

2.3 Sieve Analysis

Sieve analysis was performed in order to compare the physical properties of sand and bottom ash.

For this sieve analysis test 0.6617 kg weight of oven dried bottom ash and 1.5kg weight of oven dried sand were used. The sieve sizes used were 0.075mm, 0.25mm, 0.425mm, 0.6mm, 0.85mm, 1.18mm, 1.7mm and 2.36mm. Shaking was done for about 10 minutes using the mechanical shaker (Figure 3). The weights of the retained samples with the sieve were measured.
Fineness modulus is an empirical value obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100. Fineness modulus was obtained from the particle size distribution. Cumulative percent retained for each sieves based on the dry mass of the total sample was calculated using Eq. (1).

\[
Cumulative Percent Retained = 100 \left( \frac{Cumulative \ Mass \ Retained}{Mass \ of \ Total \ Sample} \right)
\]  

(1)

After calculating the cumulative percent retained, fineness modulus was obtained using Eq. (2).

\[
Fine Modulus = \frac{\sum Cumulative \ Percent \ Retained}{100}
\]  

(2)

2.4 Specific Gravity

Specific gravity of both sand and bottom ash was determined using density bottle method as specified in ASTM D-85400.

An oven dried and cooled sample of sand and bottom ash were selected. The weights of the empty, clean and dry density bottles were measured. The sample was placed in the density bottle and the weights of the density bottle containing the dry samples were measured. Distilled water was added to fill about half to three-fourth of the density bottle and the samples were soaked for half an hour. Then a partial vacuum was applied to the contents for 20 minutes, to remove the entrapped air (Figure 4). Later, the density bottle was filled with distilled water and the weight of the density bottle and contents was measured. Specific gravity of the sample was determined using Eq. (3),

\[
Specific gravity = \frac{W_s}{W_0 + (W_A - W_B)}
\]  

(3)

where,

\(W_0\) = weight of oven-dry sample, g

\(W_A\) = weight of density bottle filled with water

\(W_B\) = weight of density bottle filled with water and the sample
The test was performed for three samples of each material: bottom ash and sand. An average value was considered as the specific gravity of the materials.

![Figure 4: Applying partial vacuum during specific gravity testing](image)

### 2.5 Water Absorption

Water absorption was determined for three samples of each replacement level and the average of the three values was considered. Samples were kept under normal environmental condition for 7 days and 28 days to obtain the water absorption at the air dry condition where there is no surface moisture, only internal moisture. When the samples were kept under normal condition, the dry weight of the blocks was measured. Then the same blocks were immersed in water for a period of 24 hours and the weights of the blocks were measured. Water absorption was quantified as percentage of ratio of the reduction in weight to the dry weight of the blocks.

### 2.6 Workability

Workability was determined in terms of compaction factor where compaction factor is equal to the ratio between partially compacted concrete weight and fully compacted concrete weight.

### 2.7 Compressive Strength

The compressive strength of the paving blocks was determined according to BS 6717-1 (1993), British Standard for precast paving blocks using the compression testing machine. The blocks were tested in 7, 28 and 56 days. However, determination of the long term performances is very important as bottom ash is a degradable material and consists with high amount of SiO$_2$ (Kasemchaisiri and Tangtermsirikul, 2008) which takes time to react. Three blocks were tested for each replacement level of bottom ash and the average compressive strength was determined.

Plan area was determined before storing it in water and later the blocks were cured. The compression testing machine (Figure 5) was cleaned and steel plates were placed between the upper and lower faces of the block and the machine platens. The blocks were placed in the machine with the wearing surface in a horizontal plane and in such a way that the axes of the block are aligned with those of the machine platens. Then the load was gradually applied and the maximum load applied to the block was recorded. Compressive strength was determined by dividing the maximum applied load from the plan area and multiplying by the correction factor. Correction factor for 70 mm thickness blocks as per Sri Lankan Draft Standard is 1.06.
Figure 5: Compression testing machine

Determination of plan area is different from the typical paving blocks as the blocks are “S” in shape. The plan area of the S type block was determined as follows. The block was placed, wearing surface uppermost, on the cardboard and the perimeter was traced with a pencil (Figure 6). A rectangle measuring 200 mm x 100 mm was cut accurately from the same cardboard.

Figure 6: Tracing around the perimeter of the block

The plan area of the block was calculated using Eq: (4).

\[ A_s = \frac{20000m_s}{m_r} \]  

(4)

where,

- \( A_s \) = Plan area of the paving block
- \( m_s \) = Mass of the cardboard shape matching the block (g)
- \( m_r \) = Mass of a 200 mm x 100 mm cardboard rectangle (g)

3.0 Results and Discussion

3.1 Sieve Analysis

The particle size distribution of bottom ash and sand was obtained from sieve analysis test and is compared in Figure 7.
Figure 7: Particle size distribution curves of bottom ash and sand

Fineness modulus for both sand and bottom ash are shown in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Fineness Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>4.86</td>
</tr>
<tr>
<td>Bottom ash</td>
<td>3.08</td>
</tr>
</tbody>
</table>

It has been observed that both bottom ash and sand have different size of particles at different percentage. Both bottom ash and sand can be considered as reasonably well graded materials.

The particle size distribution curves found in the current study (Figure 7) are very similar to the curves found in a previous study by Erandi et al (2013). Normally the properties of bottom ash are changed from the plant to plant (Abdulhameed and Khairul, 2012). The similarity found in the current study may be because bottom ash had been obtained from the Norachcholai coal power plant for both studies.

When considering about upper limit and lower limit (ASTM C33-03) sand slightly deviates from lower limit and bottom ash slightly deviates from upper limit (Figure 8).
Fineness modulus of sand is greater than that of bottom ash (Table 1). According to the previous study by Kadam and Patil, (2013), the fineness modulus for sand and bottom ash was 3.75 and 2.7 respectively. There is a significant difference between the fineness modulus found in the current study and in the previous study. This may be because the changes in the specific gravity values of both sand and bottom ash. The specific gravity of sand and bottom ash obtained by Kadam and Patil, (2013) was reported as 2.62 and 1.93, respectively.

3.2 Specific Gravity

Specific gravity of bottom ash and sand is shown in Table 2.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>2.72</td>
</tr>
<tr>
<td>Bottom ash</td>
<td>2.10</td>
</tr>
</tbody>
</table>

Table 2: Specific gravity of bottom ash and sand

It has been reported that natural aggregates have specific gravity between 2.6 and 2.8 (Shetty, 2005). The specific gravity obtained for sand in the current study is 2.72 (Table 2) and in the range reported by Shetty (2005) (between 2.6 and 2.8). The specific gravity of bottom ash was 2.1. According to the current study, the specific gravity of bottom ash is less than the specific gravity of sand (Table 2). The reason for that may be because bottom ash is a porous material.

Specific gravity of bottom ash found in the current study (Table 2) was mostly similar to the value found in a previous research study (i.e., 2.08) (Erandi et al, 2013) where the bottom ash was collected from the Norachcholai coal power plant, Sri Lanka. The specific gravity of bottom ash is less than that of sand. Therefore light weight paving blocks can be manufactured when bottom ash is used as a replacement with sand.

3.3 Water Absorption

Water absorption property of each block was investigated and average water absorption was determined by averaging three corresponding values. The average water absorption obtained is shown in Figure 9.

![Figure 9: Average water absorption of paving blocks with different replacement level of bottom ash](image)
From Figure 9 it can be seen that the water absorption was increased with increasing the bottom ash replacement level. However water absorption of control specimen (0% replacement level) is slightly higher than the water absorption of 10% replacement level.

### 3.4 Workability

Workability of each mix is shown in Table 3. Workability measured in terms of compaction factor was decreased with increasing the level of replacement of bottom ash.

#### Table 3: Compaction factor for each replacement level of bottom ash

<table>
<thead>
<tr>
<th>Replacement level (%)</th>
<th>0</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compaction factor</td>
<td>0.97</td>
<td>0.90</td>
<td>0.87</td>
</tr>
</tbody>
</table>

This might be caused by the difference in fineness of bottom ash and sand. Due to the increasing in the fineness, surface area of bottom ash increases. As a result bottom ash particles tend to absorb more water. Therefore particles get into a more closed packing resulting decrease of workability.

### 3.5 Compressive Strength

Compressive strengths at the age of 7 days, 28 days and 56 days are shown in Table 4 and Figure 10.

#### Table 4: Variation of average compressive strength with the age of paving blocks

<table>
<thead>
<tr>
<th>Replacement Level (%)</th>
<th>Average Compressive Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 days</td>
</tr>
<tr>
<td>0</td>
<td>17.5</td>
</tr>
<tr>
<td>10</td>
<td>15.5</td>
</tr>
<tr>
<td>20</td>
<td>13.3</td>
</tr>
</tbody>
</table>

![Figure 10: Compressive strength of paving blocks with bottom ash with age](image)

90
According to Table 4, it can be seen that the compressive strength reduces with the increasing of the replacement level of bottom ash. The rate of change of compressive strength increases with increasing the replacement level of bottom ash at 7 days, 28 days, and 56 days. For the age of 7 days, the rate of change of compressive strength with respect to the control block, i.e., 0% replacement level, for 10% replacement level and 20% replacement level is about 11% and 24%, respectively and for the age of 28 day, the rate of change of compressive strength with respect to control block, for 10% replacement level and 20% replacement level is about 7% and 27% respectively. For the age of 56 days, the rate of change of compressive strength with respect to the control block, for 10% replacement level and 20% replacement level is about 11% and 18% respectively. The reduction of compressive strength with the increasing of the replacement level may be because bottom ash is not as strong as the sand. However, utilization of bottom ash, which is a waste material, at an appropriate level to achieve a reasonable strength will be an advantage: material cost of paving block can be reduced with reducing the accumulation of waste material in environment.

The strength gain of the paving blocks increases with the age, for all the replacement levels. For 0% replacement level, strength gain for the ages of 28 days and 56 days is 45% and 55%, respectively. For 10% replacement level, strength gain for the ages of 28 days and 56 days is 52% and 56%, respectively and for 20% replacement level, strength gain for the ages of 28 days and 56 days is 40% and 67%, respectively. High strength gain of paving blocks with the age can be seen for the 20% replacement level of bottom ash, implying that in terms of strength gain, 20% replacement level is best.

As per Sri Lankan Draft Standards (2011), the average compressive strength of paving blocks required for foot paths is 15 N/mm². Seven day compressive strength of control specimens and 10% replacement level specimens satisfy the requirements (Table 4). However, 20% replacement level does not satisfy with the requirements of Sri Lankan Draft Standards (2011), implying that the 20% replacement level is slightly high to use in paving blocks which require immediate usage (i.e., within 7 days). Twenty eight day and 56 day compressive strength of all replacement levels satisfied the requirement of Sri Lankan Draft Standards (2011). As per the standards, required individual compressive strength is 12 N/mm². Individual compressive strength of paving blocks at the ages of 7 days, 28 days and 56 days in each replacement level of bottom ash (i.e., 0%, 10% and 20%) satisfies the requirement, although compressive strengths of individual blocks are not presented in this paper.

4.0 Conclusions

Bottom ash which is a by-product of coal combustion process has the properties of construction materials.

It was found that specific gravity of bottom ash is, 2.10, which is less than that of sand, 2.72. However, the fineness modulus of bottom ash, 4.86, is greater than that of sand, 3.08.

Compressive strength of paving blocks was investigated at different ages: 7 days, 28 days and 56 days. It was found that compressive strength decreases with the increasing of the replacement level of bottom ash. At 10% replacement level, the compressive strength for 7 days, 28 days and 56 days was found to be 15.5 N/mm², 23.5 N/mm² and 24.18 N/mm², respectively, satisfying the compressive strength requirement of Sri Lankan Draft Standards. Twenty eight day and 56 day compressive strength for 20% replacement level were found to be 18.6 N/mm² and 22.2 N/mm², respectively and also satisfies the requirement of Sri Lankan Draft Standards. However, 20% replacement level compressive strength for 7 day age was found as 13.3 N/mm², which slightly deviates from the requirement.
Water absorption of paving blocks increases with the increasing of the replacement level of bottom ash and workability, which was determined in terms of compaction factor, decreased with the increasing of the replacement level of the bottom ash.

The paving blocks cast with bottom ash have required compressive strength and other properties, implying that bottom ash can effectively be utilized in manufacturing paving blocks.

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References


AMERICAN SOCIETY FOR TESTING AND MATERIALS, ASTM C33-03: Standard Specification for Concrete Aggregates


