# BOTTOM ASH AS REPLACEMENT OF SAND FOR MANUFACTURING MASONRY BLOCKS

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## Abstract

Bottom ash is a waste material from coal combustion and has no specific utilization in Sri Lanka. Usually, they are disposed into environment as a waste material. Bottom ash is a light-weight material, which consists of considerable amount of $SiO_2$. Objective of this study is to utilize bottom ash as replacement of sand for manufacturing masonry blocks. Properties of bottom ash and the structural properties of masonry blocks manufactured with bottom ash were investigated.

Solid masonry blocks having the size 360 mm x100 mm x 170 mm were cast with a mix proportion of 1:6 Cement: Sand. Bottom ash, as replacement for fine aggregates, was used in varying percentages: 0%, 10%, 20% and 30%. Compressive strength was determined by crushing the masonry blocks at the ages of 7, 14 and 28 days. In addition, water absorption properties and material cost of the blocks were investigated.

It was found that utilization of 20 % of bottom ash for replacement of sand provides greater compressive strength. Structural properties and cost of the bottom ash based blocks are discussed in this paper.

**Keywords:** Bottom ash, weight reduction; cement sand blocks, compressive strength, replacement level

# 1. Introduction

Bottom ash refers to part of the non-combustible residues of combustion. It usually refers to coal combustion and comprises traces of combustibles embedded in forming clinkers and sticking to hot side walls of a coal-burning furnace during its operation. Fly ash is another by - product of coal combustion. Fly ash has already been utilized in the construction industry as a partial cement replacement and or mineral additive in cement production. The utilization of Bottom Ash (BA) is limited due to various reasons including its relatively higher unburned carbon content and inconsistency of properties compared to fly ash.

In Sri Lanka recently bottom ash is available as a result of an installation of coal power plant in Norachcholai area. However, in Sri Lanka, bottom ash is not utilized for any purpose. It is dumped to the land and sometimes land may become unusable land due to the improper dumping. Therefore, proper utilization of BA will utilize the waste as well as save the natural resources for building construction.

Bottom ash (Figure 1), is a light-weight material. Light-weight structural materials (i.e., mortar and concrete) have many advantages. If light-weight concrete with high-strength is realized, the section size of members may be reduced due to lighter dead load of structural elements. This may permit not only large space availability but also a reduction in quantity of cement and reinforcement.

Nowadays, there are many construction projects going on in Sri Lanka. It needs lot of raw material such as sand, coarse aggregates and cement. Due to higher utilization, these natural materials will be scare. Alternatives to replace them are an urgent requirement. Fly ash which is produced due to incineration of coal is already used to produce cement; however, there is no alternative for sand. Bottom ash, which is hard and light weight, is a good alternative for sand. Objective of the current study is to utilize bottom ash as replacement for sand in manufacturing of masonry blocks. Optimum utilization of bottom ash and properties of bottom ash based blocks are investigated.

Figure 1: Bottom Ash

# 2. Methodology

## 2.1 Selection of the material

Material selection for the replacement of sand was done by considering the physical properties. Bottom ash (BA) was collected from the Norachcholai coal power plant. The clean, sharp river sand that was free of clay, loam, dirt and any organic or chemical matter as specified in Sri Lanka Standard 855 (1989) was used in the current study. Ordinary Portland Cement (OPC) as specified in Sri Lanka Standard 855 (1989) was used. Potable water that was collected from pipe born water of National Water Supply and Drainage Board (NWS&D) was used. Water was free from organic matter as specified in Sri Lanka Standard 855 (1989).

## 2.2 Block manufacturing

Conventional solid masonry blocks with the size of 360 mm x 100 mm x 170 mm were cast with the mix proportion of 1:6; cement: sand (volume basis). Bottom ash based blocks were manufactured using bottom ash at four different level of replacement (i.e., 10%, 20%, 30%, and 100%) for sand with the same dimensions. In order to prepare mortar, the cement, sand and bottom ash were thoroughly mixed and then the mixture was turned over number of time. The water was added to the mixture while maintaining 0.7 water-cement ratio. Higher water-cement ratio was required as bottom ash absorbed more water. The mixture was further turned over by using shovels until achieving a mix of the required workability as described in the previous study, where blocks were manufactured using Rice Husk Ash (RHA) (Pushpakumara and Subashi (2012)).

The steel mould attached to a local block manufacturing machine was completely filled with the mortar (i.e., 170 mm height) (Figure 2) and vibro-compaction was applied for 10 seconds. Additional mortar was filled to the mould and vibro-compaction was applied for another 10 seconds to prepare the block. After removing blocks from the mould, they were left on the ground.

Twenty four hours after manufacturing the blocks, they were continuously cured until the day of testing. Curing process was carefully done as the strength gained by the blocks depends upon the curing of the blocks. Blocks were cured by sprinkling water onto the blocks twice a day.

Figure 2: Block Manufacturing

## 2.3 Laboratory Experiment

### 2.3.1 Specific gravity

Specific gravity for both sand and bottom ash was tested by a laboratory experiment, which is recommended to determine the specific gravity of sand. Following procedure was carried out. Empty weight of glass container was measured ($W_p$). Then approximately 10-15g of material (i.e., bottom ash or sand) was filled to the glass container. The container weight with material was measured ($W_{ps}$). Weight of material was determined by Equation (1). Distilled water was added to the container and weight was measured ($W_o$). The container was partially submerged in the boiled water until all the air bubbles blow out from the container. After the container was cooled properly, distilled water was applied to the container until it fills properly ($W_b$)**.** Equation (2) was used to calculate the specific gravity. This procedure was repeated for bottom ash also.

$$W = W_{PS} - W_P \text{ ----------------------- (1)}$$

$$\text{Specific gravity} = \frac{W}{W_0 + W - W_b} \text{ ------------------------ (2)}$$

### 2.3.2 Compressive strength

The concrete crushing machine (Figure 3) available in the Building Materials Laboratory was used to investigate the compressive strength at different age of the blocks. Conventional blocks (1:6 Cement: Sand blocks) and BA based blocks were tested at the age of 7, 14 and 28 days. For each type of blocks, three blocks were tested. Average compressive strength was determined by averaging corresponding measurements for three blocks.

Figure 3: Concrete crushing machine

### 2.3.3 Water absorption

Water absorption properties of both cement sand block and bottom ash based block were investigated. The samples were kept in an oven at a temperature of $100^0$C-$105^0$C for 24 hours and dry weights of the blocks were measured. Then the same samples were immersed into the water for a period of 24 hours and wet weights were measured after drying the surface. Water absorption was calculated for both cement sand and bottom ash based blocks as mentioned in a previous study by Pushpakumara and Subashi (2012).

### 2.3.4 Cost Analysis

Cost analysis was performed only considering the cost of material for manufacturing each type of blocks. Cost of block manufacturing usually includes cost of material, labour and machinery. As the cost of machinery and labour are the same for manufacturing of the both, BA based and conventional blocks, cost of material was only considered for this cost analysis. In the cost analysis, no expenditure for BA was considered as it is a waste material. The cost of cement bag (50 kg) was considered as Rs.820.00 and $100ft^3$ of sand was considered as Rs. 8000.00. Volumes of the cement, sand were calculated according to the particular proportions for blocks. Costs of the blocks were determined by multiplying material quantity by unit price of materials. Current investigation was conducted in Galle, which is about 250 km far away from Norachcholai coal power plant. Therefore, it is not appropriate to add transportation cost of bottom ash to this analysis. If the block manufacturing yard can be placed at Norachcholai area the transportation cost of bottom ash will be minimum.

# 3. Results and Discussion

## 3.1 Specific gravity

Table 1 shows specific gravity for bottom ash and sand. It can be seen from Table 1 that the bottom ash has lesser specific gravity than sand.

*Table 1: Specific gravity of bottom ash and sand*

| *Material* | *Specific gravity* |
|---|---|
| *Sand* | *2.67* |
| *Bottom ash* | *1.98* |

Specific gravity of both sand and bottom ash found in the current study can be compared with the specific gravity reported in a previous study (US Department of transportation) (Table 2). As both studies were conducted on the coal bottom ash this direct comparison of values may be appropriate.

*Table 2: Comparison of specific gravity*

| *Material* | *Present study* | *Previous study by US Department of transportation* |
|---|---|---|
| *sand* | *2.67* | *2.67* |
| *Bottom ash* | *1.98* | *2.1-2.7* |

The specific gravity found in the current study is comparable with the specific gravity reported in the previous study (US Department of transportation). In the previous study, it has been found that the specific gravity of sand is 2.67 while the specific gravity of bottom ash varies between 2.1-2.7 (US Department of transportation). In the current study, specific gravity of sand is 2.67 while specific gravity of bottom ash is 1.98. Both studies found that bottom ash is generally lighter, although the upper limit of specific gravity of bottom ash is slightly higher than that of sand.

Sand has the similar value which is 2.67. Reduced specific gravity of bottom ash has contributed to weight difference between two types of blocks: bottom ash based blocks are lighter than conventional cement-sand blocks as reported in the previous study (Anthony et al, 2012).

## 3.2 Compressive strength

Compressive strength of each block was obtained from the concrete crushing machine. Three corresponding measurements were averaged and it was defined as average compressive strength of blocks. The average compressive strength values are shown in Table 3.

*Table 3: Average compressive strength of cement sand blocks for different bottom ash replacement levels.*

| *Sample Identification* | *BA contents* | *Average compressive strength ($N/mm^2$)* | | |
|---|---|---|---|---|
| | | *7 Day* | *14 Day* | *28 Day* |
| *Sample 1* | *0%* | *2.729* | *3.018* | *3.906* |
| *Sample 2* | *10%* | *2.098* | *2.194* | *3.564* |
| *Sample 3* | *20%* | *2.356* | *2.472* | *3.679* |
| *Sample 4* | *30%* | *1.321* | *1.384* | *2.044* |
| *Sample 5* | *100%* | *1.087* | *1.583* | *1.603* |

However, exceptionally low or high compressive strength values were neglected and at least two corresponding readings were considered for the above calculation. Average compressive strength was determined for bottom ash based cement sand blocks with replacing sand by different percentages of bottom ash and for conventional cement sand blocks. Variation of strength with the replacement level of BA is shown in Figure 4**.**

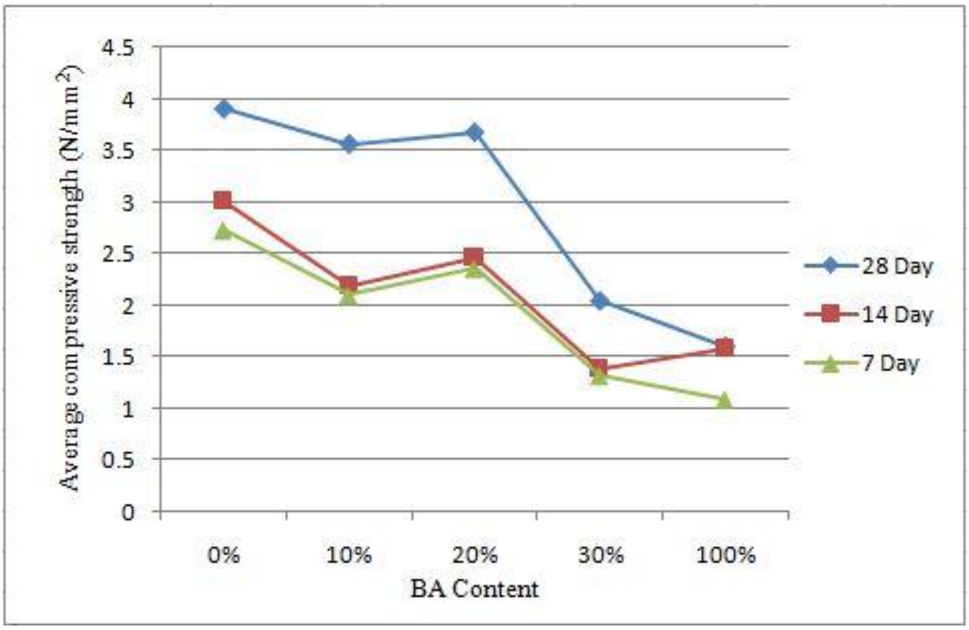


Figure 4: Average compressive strength of cement sand blocks for different bottom ash replacement levels

It can be seen from Figure 4 that the average compressive strength of the blocks increases with the age of the blocks. Compressive strength of conventional block (i.e. 0% BA) has 3.906 $N/mm^2$ while 20% BA based block has 3.679 $N/mm^2$ in 28 days (Table 3). In addition, 10% BA based block shows 28day compressive strength as 3.564 $N/mm^2$. Further increases in BA level from 20 % show reduction in the compressive strength (Figure 4). This trend is similar irrespective of the age of blocks. Among the blocks manufactured with BA, the block with 20% BA replacement level has the highest compressive strength.

Compressive strength is one of the main governing parameter for building materials in Civil Engineering construction, especially in concrete and structural elements such as cement sand blocks. Although there are many parameters which should be considered while choosing a quality product, compressive strength obviously has major impact on the product. In the current study, 28 day compressive strength values are greater than the minimum required value (i.e., 2.8 $N/mm^2$) (BS 6073: Part 2: 1981).

It is clearly observed that the 20% BA replacement level has the highest compressive strength among the blocks manufactured with bottom ash (Figure 4). This compressive strength is greater than the required standard value (i.e., 2.8 $N/mm^2$ published in BS 6073: Part 2: 1981). The 10% replacement level of bottom ash has shown a compressive strength about 3.5 $N/mm^2$, which is also greater than the minimum required value. This emphasizes that the optimum replacement level of bottom ash is 20% of sand. While considering about 20% bottom ash replacement level, it is 31.4% greater than the compressive strength with respect to minimum required value (i.e., 2.8 $N/mm^2$).

In the current study, the blocks were manufactured with local block manufacturing machine. In this type of machinery, a short period of vibro-compaction and manual compaction using a lever-arm are applied. However, with advanced machineries, where compaction is applied by using hydraulic pressure, can be used to produce BA based blocks with higher compressive strength than that found in the current study.

## 3.3 Water absorption

Water absorption property of each block was investigated and average water absorption was determined. Average water absorption was calculated by averaging three corresponding values. The results obtained are shown in Table 4.

The acceptable value of water absorption is 12% for masonry blocks according to BS 5628: Part 1 (2005). In the current study, except 100% bottom ash replaced block, each block has the water absorption value, which is within the allowable limit. Conventional cement sand block has the water absorption percentage of 7.29%, which is also well within the acceptable range. While considering about 100% replacement of bottom ash it has the highest water absorption percentage (i.e., 24.03%), which implies that the bottom ash is a water absorbable material. This may be due to the increase of porosity due to the replacement of sand. In addition, bottom ash is generating due to the combustion of coal so it may consist some dry particles which obviously tends to absorb some water. Although 100% bottom ash replacement has higher water absorption value, 10%, 20% and 30% replacements showed 10.42%,10.73% and 10.73% ,respectively, which are within the limit(i.e.,. below 12% BS 5628: Part 1(2005)). Furthermore it is clearly seen that the increase of bottom ash amount increases the water absorption percentage.

*Table 4: Average water absorption*

| *Sample Identification* | *BA Contents* | *Average water absorption (%)* |
|---|---|---|
| *Sample 1* | *0%* | *7.29* |
| *Sample 2* | *10%* | *10.42* |
| *Sample 3* | *20%* | *10.73* |
| *Sample 4* | *30%* | *10.73* |
| *Sample 5* | *100%* | *24.03* |

It can be seen from Table 4 that water absorption increases with increasing the level of replacement of sand by using bottom ash.  However, this is well clear with higher amount of bottom ash: 100% bottom ash replacement has the highest percentage, about 24%. Other replacement levels of bottom ash have approximately equal water absorption values (i.e., about 10-11%).

## 3.4 Cost analysis

As mentioned in the preceding section, cost comparison was done considering no expense for bottom ash and equal machine and labour cost for manufacturing each block. Material cost for manufacturing each block type is compared in Table 5.

*Table 5: Cost of materials for blocks:*

| *Sample Identification* | *BA contents* | *Material cost (Rs.)* | *Savings per block (Rs.)* |
|---|---|---|---|
| *Sample 1* | *0%* | *35.45* | - |
| *Sample 2* | *10%* | *33.93* | *1.52* |
| *Sample 3* | *20%* | *32.49* | *2.96* |
| *Sample 4* | *30%* | *31.00* | *4.45* |
| *Sample 5* | *100%* | *20.63* | *14.82* |

It can be seen from Table 5, the amount of money saving increases with increasing the replacement level of bottom ash for sand. This is due to the utilization of bottom ash which is actually a waste material from coal combustion. They are 4.28%, 8.35%, 12.55% and 41.81% saving on the cost of raw material per block due to replacement of sand by bottom ash.

The total material cost requires to manufacture conventional cement sand block is about Rs.35.45. The total material cost requires to manufacture 10%, 20%, 30% and 100% bottom ash based blocks are Rs. 33.93, Rs.32.49, Rs.31.00 and Rs.20.63, respectively.

Bottom ash, used in the current study is a waste material from coal combustion at Norachcholai coal power plant. This waste is dumped to a remote place and with the time the dumped land become an unusable land. Therefore, utilization of waste will provide many benefits. In the current study, it was observed that no expense for bottom ash and that will provide considerable benefit. The total material cost requires to manufacture conventional cement sand block is about Rs.35.45 (Table 4).

Optimum compressive strength of blocks was found at 20 % replacement level of bottom ash. Compressive strength at this replacement level is greater than the minimum required value recommended by BS 6073: Part 2 (1981). For this block, the water absorption is also within the allowable limit specified in BS 5628: Part 1(2005). It was found that for this block, about

Rs 3.00 (i.e., 10 % of material cost) can be saved. This study confirmed that the use of bottom ash in manufacturing of masonry blocks reduces environmental pollution and also reduces the cost of material for block manufacturing. This block also has additional advantage as light-weight blocks: compared to conventional cement-sand blocks, it is around 1.5 kg weight reductions per block, as presented in Anthony et al (2012).

# 5. Conclusions

Bottom ash is by-product from the combustion of coal. Recent installation of coal power plant in Norachcholai area produces bottom ash and they have no proper utilization.

It was found that the optimum level of utilization of bottom ash as replacement of sand was 20 %. The blocks, which were manufactured with 20% bottom ash as replacement of sand, showed compressive strength of 3.68 $N/mm^2$, implying that the blocks can be used to construct load bearing walls. Water absorption of this block was found as 10.7 %. Bottom ash released from Norachcholai power plant has specific gravity of 1.98 whereas sand has specific gravity of 2.67. Therefore, the blocks manufactured with bottom ash are considerably lighter than the conventional blocks. Bottom ash can be used as a raw material to manufacture light-weight masonry blocks with required structural properties.

Bottom ash based blocks are cost effective and help to utilize the waste material and prevent the environmental pollution caused by open dumping of bottom ash which obviously creates more problems.

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# References

Anthony C.S.K.R, Abeykoon A.J.M.S.S and Subashi De Silva G.H.M.J. (2012), "Properties of Masonry Blocks Manufactured with Bottom Ash*" Proceedings of 2 nd Annual Sessions of the Society of Structural Engineers, Sri Lanka (SSESL*) pp 17-23.

British Standard 5628-Part 1: 2005 Code of practice for the use of masonry. Structural use of unreinforced masonry.

British Standard 6073-Part 2: 1981 Precast concrete masonry units. Methods for Specifying precast masonry units.

Pushpakumara B.H.J. and Subashi De Silva G.H.M.J. (2012), "Characteristics of masonry Blocks manufactured with Rice Husk Ash and Lime" *Engineer, Institution of Engineers, Sri Lanka (IESL),* Vol XXXXV, issues 3, pp 1-10 .

Sri Lanka Standard 855: 1989, Specification for cement blocks

US Department of transportation, Federal highway administration, "User guidelines for waste and by product materials in pavement construction", Publication Number FHWA-RD-97-148