Journal of Engineering and Technology
The Open University of Sri Lanka (JET-OUSL), Vol. 10, No.2, pp. [9-23], 2022

Effect of Coal Bottom Ash on the properties of Cement Mortar

R. M. I. E. Piyarathne[1], K. M. L. A. Udamulla[2*]

[1] Department of Civil and Environmental Engineering, Faculty of Science and Engineering, University of Wolverhampton, Wolverhampton, United Kingdom.
[2*] Department of Civil Engineering, Faculty of Engineering Technology, The Open University of Sri Lanka, Nawala, Sri Lanka.

*Corresponding Author: email: laudu@ou.ac.lk, Tele: +94771388029

Abstract - *Disposal of bottom ash is a major problem globally in general and Sri Lanka in particular. Several approaches exist to augment its beneficial use. An attempt has been made to assess the effect of coal bottom ash on the properties of cement mortar using bottom ash. Therefore, the main objective of this research is to study the feasibility of using the bottom ash as fine aggregate in place of natural fine aggregate in the production of cement mortar. In this research two mortar designations have been considered. These two designations are mainly focused to plastering and rendering purposes. Designation (iii) is 1: 5 mix (cement: sand) and designation (iv) is 1: 6 mix proportions as per BS EN 998 –* 1-2003*. Sand replacement ranged between 0 and 40 % in steps of 10% by volume while water to cement ratio is kept constant at 1.4: 1 for designation (iii) and 1.7:1 for designation (iv). The study revealed 30% replacement of sand in mortar achieved the highest compressive strength. It was also observed that when increasing the bottom ash replacement, workability of fresh mortar decreases and the density of fresh as well as hardened mortar decreases while water absorption of hardened mortar increases* for both designations*. The 30% of bottom ash replacement gives the best performance for both designations.*

Keywords*: Masonry Mortar, Sand, Bottom Ash, Workability; Compressive Strength, Flexural Strength, Water Absorption*

1 INTRODUCTION

Mortar is a material used to bind blocks, bricks, and stones together while filling the gaps between them and for bedding and plastering during building construction. Generally, mortar consists of sand, water, and a binder such as cement or lime. As the country Sri Lanka continues to develop and urbanize at a rapid rate, the need for cement mortar becomes an essential part of town and city development and expansion. The different types of waste materials are directly dumped to the environment, and this causes environmental pollution. There is an urgent need to find ways to handle such waste owing to growing environmental concerns. Therefore, there is a growing need to reuse and recycle the waste for different construction purposes so that this will reduce the burden on natural resources as well.

The use of waste material in producing cement mortar could be a viable solution for the recovery and recycling of waste materials. Out of various types of waste materials in Sri Lanka, Bottom Ash (BA – coarse, granular material collected from the bottom of a coal furnace) is a novel waste material disposed from Norochcholai power plant. Bottom ash is lighter and more brittle and is dark grey material with a grain size similar to that of sand (Bajare et al., 2013). It is composed of silica, alumina, and iron with small amounts of calcium, magnesium, and sulphate. Grain size typically ranges from fine sand to gravel in size (Kumar et al., 2014). In the Norocholai power station, 2500 MT of coal is burnt per day when plant running at 300 MW and it produces 250 MT of fly ash and bottom Ash at a rate of 25 MT per day (Ranjan & Nanayakkara, 2013). At present, Sri Lanka is faced with a major problem in disposing this bottom ash as a result of the installation of coal power plant in Norachcholai area.

Earlier works by other researchers on fly ash and bottom ash usage for cement/sand replacement in concrete and mortar mixes in building construction are reviewed and discussed herein. Brake et al., (2017) had explored the re-usability of coal bottom ash as cement replacement in mortar. The sub -bituminous bottom ash was made pulverized using a high energy vibratory ball mill at two different milling times to achieve a particle fineness approximately two and three-times finer, respectively, than type I cement and the effect on workability and setting time were studied. The results revealed that coal bottom ash can be pulverized with a high energy ball mill to produce a re-utilizable pozzolan that, can significantly increase the strength activity, improve the microstructure of cement mortar, and increase the cement replacement tolerances without significant reduction to compressive strength. Hyeong (2015) had experimented with sieved and ground coal bottom ash in high strength cement mortar. The bottom ash powder was observed to increase the workability and compressive strength values than the equivalent mortar made of cement and fly ash due to the high pozzolanic reactivity. Janardhanan and Venkatasubramani (2015), proposed to utilize ground bottom ash in geo-polymer mortar. Influence of alkaline activator, Molar ratio and curing mode on compressive strength of such mortars were studied. With different molar ratio with different activator, improvement in compressive strength was observed under both ambient curing and steam curing atmospheres respectively. Shahiron (2016), had investigated whether coal bottom ash can be used as a replacement material for sand. The specific gravity, particle size distribution, density, scanning electron microscopy and X-ray fluorescence tests were carried out. The results indicated that the angular porous structure and the rough texture of bottom ash affected its particle density and specific gravity on the lower magnitude than that of sand. It was revealed that both the sand and bottom ash have similar gradations. The results indicate that overall, bottom ash can be used favourably as a replacement material to sand. Mahapara et al., (2016) had studied whether coal bottom ash can be used as partial replacement of sand and waste limestone dust as partial replacement of cement in concrete. The result showed that at fixed W/C ratio the compressive strength, flexural strength, split tensile strength and durability increased initially at small percentages and later when the percentage of replacement is increased the strength and durability decreased.

In this situation, the study was aimed at finding the feasibility of using bottom ash as a partial substitute to fine aggregate in producing cement mortar by considering the effects of the physical and mechanical properties of cement mortar so produced. Furthermore, rapid extraction of river sand has caused many environmental issues such as erosion of riverbeds, losing water retaining strata, deepening of riverbeds, loss of vegetation on the riverbank and due to lowering of the water table the disturbance to aquatic life. The Demand for natural sand for construction purposes has increased significantly in Sri Lanka in recent years and the cost of river sand has also increased immensely. Therefore, this study was aimed to identify whether bottom ash could be used as an alternative material to replace sand in masonry mortar to help reduce the usage of depleting resources by reducing the use of sand and minimizing environmental hazards through waste disposal by making use of bottom ash.

2 METHODOLOGY

2.1 Materials

For the preparation of mortar mix cement, sand, water, and bottom ash were used.

2.1.1 Cement

Ordinary Portland Cement (OPC) as per the Sri Lankan Standard 107 (2008) & ASTM C150 was used.

2.1.2 Aggregates

Sand and Bottom ash was used as fine aggregate. The clean, sharp river sand that was free of clay, loam, dirt and any organic or chemical matter was used. Bottom ash samples are collected from Lakvijaya Power Station. Particle sizes for mortar were tested in accordance with BS EN – 933 – 1997. Particles below 2.36 mm were used for the mortar preparation. The particle size distribution curves of sand and bottom ash are given in the Figure 1 while Table 1 depicts the physical properties such as Specific gravity, Moisture Content, Water Absorption and Loose Bulk Density of the same.

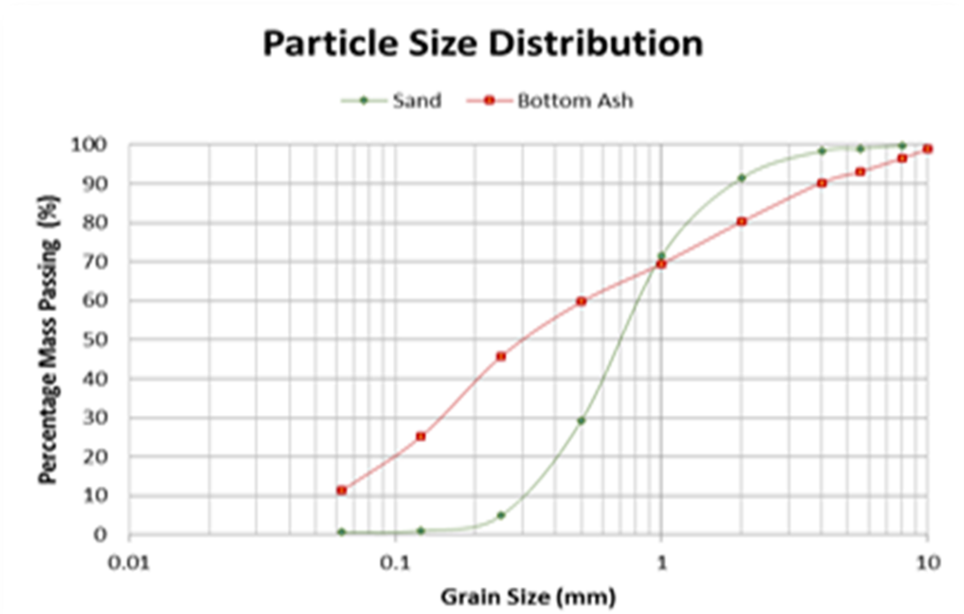

Fig. 1. Particle Size Distribution Curves of Sand and Bottom Ash

Table 1 Physical Properties

Physical Properties	Sand	Bottom Ash
Moisture Content (%)	1.99	24.07
Water Absorption (%)	0.5	19.45
Specific Gravity	2.68	1.52
Loose Bulk Density ($\mathbf{kg/m^3}$)	1480	750

2.2 Methods

2.1.1 Sample Preparation

Sample preparation of mortar was done accordance with BS 5628 – 3 – 1985 which was adopted by Specification for Rendering and plastering mortar given in BS EN 998 – 1 – 2003. Material composition for the selected mortar designation is given in the table 2. After several trials it was identified that stipulated water content for the control mix as per the BS 5628 – 3 – 1985 was not sufficient to achieve the target flow given in BS EN 1051 – 2 – 1999 and therefore suitable water content was changed accordingly. The mortar designation, cement: sand ratio and water: cement ratio used were given in table 2.

Table 2 Mortar Designation for the control mixes as per BS EN 998-1 -2003

Mortar Designation	Cement : Sand (Proportion by volume)	Water : Cement
(iii)	1:5	1.4 : 1
(iv)	1:6	1.7:1

The sand was partially replaced volumetrically with bottom ash and control mix was made in accordance with exact cement: sand ratio of mortar designation. The partial replacement of bottom ash to that of fine aggregate (sand) was according to the proportions given in Table 3. Since dry bottom ash was used no correction for w/c ratio was necessary.

Table 3 Partial replacement of sand with bottom ash

Sample Name	Sand (%)	Bottom ash (%)
A	100	0
B	90	10
C	80	20
D	70	30
E	60	40

Hand mixing method was used for mortar preparation and the samples were cast in moulds of size of 150 mm × 40 mm × 40 mm. According to the specifications, prism mould was removed after 2 days from the date of casting was done. As soon as the mortar prisms were removed, the mortar prism was inserted in sealed polythene bag and kept inside a desiccator for curing where relative humidity was provided. Mortar prisms were cured for 7 and 28 days.

Table 4 and 5 show the number of prisms that was cast to check the hardened properties of the cement mortar for the two designations.

Table 4 No. of prisms for each designation

<table>
<tr><th></th><th colspan="4">Flexural and Compressive Strength</th><th colspan="2">Water Absorption and Dry Bulk Density</th></tr>
<tr><td rowspan="4">No of Prisms</td><td colspan="2">7 days</td><td colspan="2">28 days</td><td colspan="2">14 days</td></tr>
<tr><td colspan="2">30</td><td colspan="2">30</td><td colspan="2">30</td></tr>
<tr><td>1:5</td><td>1: 6</td><td>1:5</td><td>1:6</td><td>1:5</td><td>1: 6</td></tr>
<tr><td>15</td><td>15</td><td>15</td><td>15</td><td>15</td><td>15</td></tr>
</table>

Table 5 No. of prisms for each composition

Sample Name	Bottom ash (%)	No of Prisms
A	0	3
B	10	3
C	20	3
D	30	3
E	40	3
		15

2.2.2 *Test Methods*

Workability, Compressive strength, Water absorption, fresh and dry bulk density parameters of mortar were tested according to following specifications given in the table 6.

Table 6 Test Methods with Specifications

Property of Mortar		Test Specification
Fresh State	Bulk Sampling	BS EN 1051 – 2 – 1999 [Bulk sampling of mortar sand preparation of test mortar]
	Fluidity	BS EN 1051 – 3 – 1999 [Determination of consistence of fresh mortar (by flow table test)]
	Plunger Penetration	BS EN 1051 – 4 – 1999 [Determination of consistence of fresh mortar (by plunger penetration)]
	Bulk Density	BS EN 1051 – 6 – 1999 [Determination of bulk density of fresh mortar]
Property of Mortar		**Test Specification**
Hardened State	Dry Bulk Density	BS EN 1051 – 10 – 1999 [Determination of dry bulk of density of hardened mortar]
	Compressive and flexural strength	BS EN 1051 – 11 – 1999 [Determination of Compressive and flexural strength mortar]
	Water Absorption	BS EN 1051 – 18 – 1999 [Determination of water absorption coefficient due to capillary action of hardened mortar]

3 RESULTS AND DISCUSSION

3.1 Workability of Fresh Mortar

The flow table test and plunger penetration test were carried out to assess the consistency of mortar. The results of flow table test and plunger penetration test are given in figure 2 & 3 for designation (iii) while figure 4 & 5 represents the results of the designation (iv). For all the compositions of the designations, water: cement ratio was kept constant as mentioned in table 2.

The results of designation (iii) & (iv) reveal that with the increment of the bottom ash percentage the workability decreases. The Control mix where the content of bottom ash percentage was zero percent satisfied the target flow value in accordance with BS EN 1015 – 02 – 1999. For all other compositions the target flow was not achieved. The plunger penetration results confirm the decrease in flow values with the increase of bottom ash percentage.

The results of the flow table test and plunger penetration test of designation (iv) indicates a high reduction in workability than designation (iii). This may be attributed because the designation (iv) contains more bottom ash than the designation (iii). The reduction in the flow demonstrates that the presence of bottom ash influences the workability of the fresh properties of the mortar. However, in both designations the bottom ash replacement of 10% - 30% had a considerable flow than of 40% bottom ash replacement.

Workability of Designation (iii) – (1: 5) Proportion

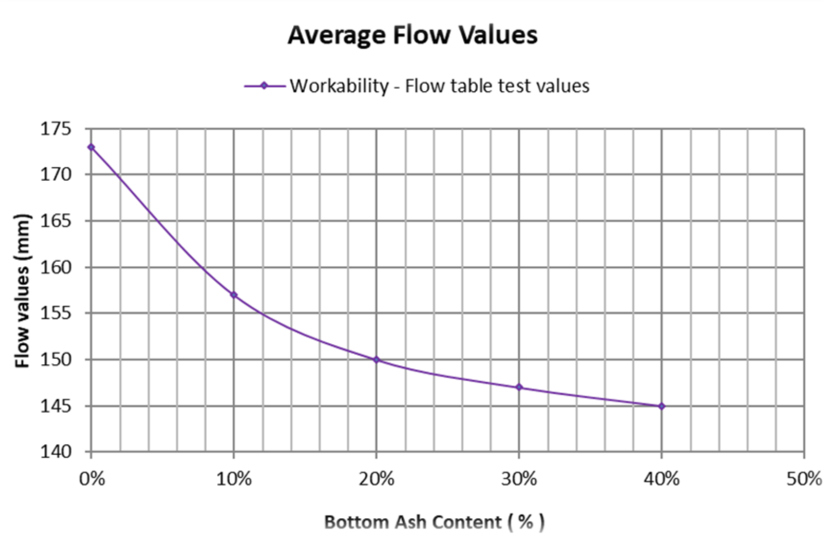

Fig. 2 Average Flow values of 1:5 Proportion

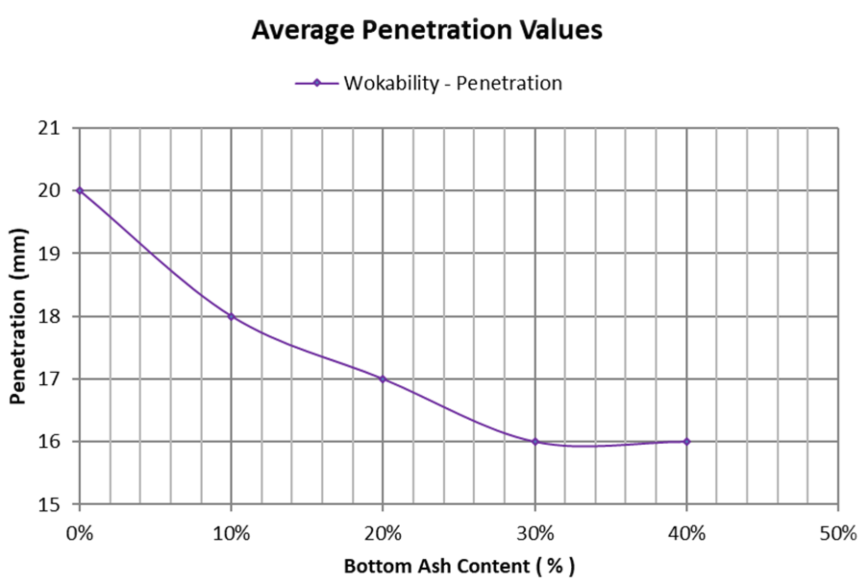

Fig. 3 Penetration values of 1:5 Proportion

Workability of Designation (iv) – (1: 6) Proportion

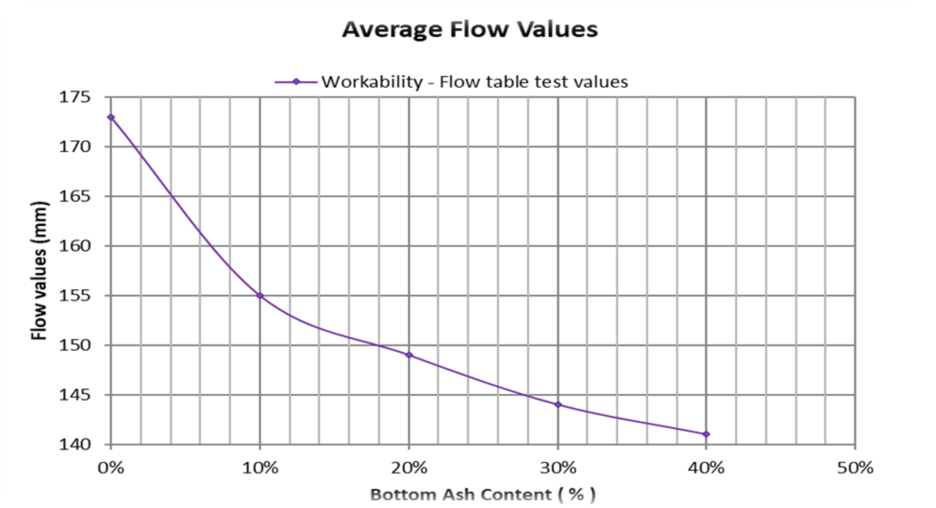

Fig. 4 Average flow value graph of 1:6 Proportion

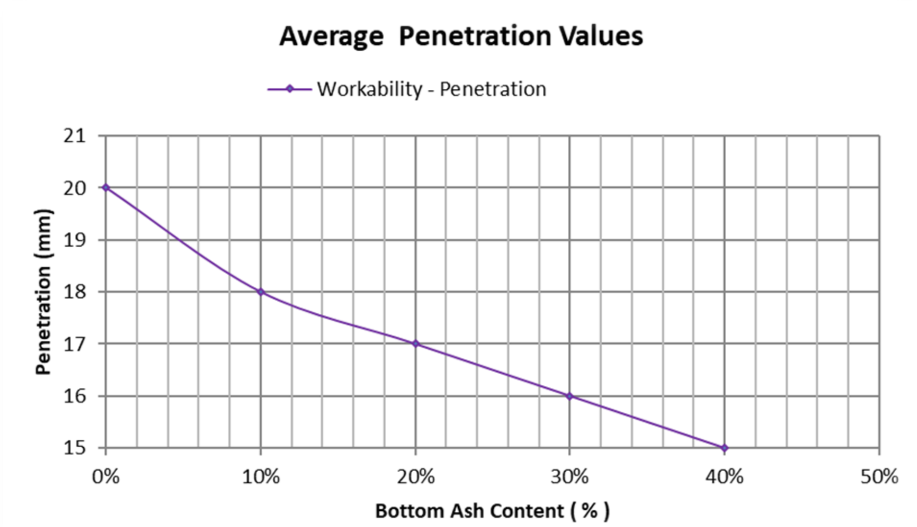

Fig. 5 Average Penetration values of 1:6 proportion

It can be due to the extra fineness of bottom ash as the replacement level of fine aggregates is increased. Thus, increase in the specific surface due to increased fineness and a greater amount of water needed for the mix ingredients to get closer packing, results in decrease in workability of the mix.

3.2 Compressive Strength of Mortar

Test results of compressive strength test are given in figures 6 & 7 for designation (iii) and (iv) respectively. As per the results so obtained, the highest compressive strength was achieved at 30% of bottom ash replacement in both designations. It was interesting to note that the compressive strength of the control sample was comparatively low compared to the bottom ash replaced samples. With the increment of bottom ash replacement, the compressive strength gradually increases and then suddenly drops at 40% replacement. The 30% bottom ash replaced samples achieved the optimum compressive strength. This may be due to the rough texture and irregular shape of particles of bottom ash which play significant role in increasing the inter particle friction, due the presence of cavities. Bottom ash particles are irregular shaped (Ghosh, et al. 2008) whereas the sand particles are spherical shaped. These two particles shapes will interlock with each other to combine a closely packed combination and hence may result in increasing the compressive strength with the additions of bottom ash.

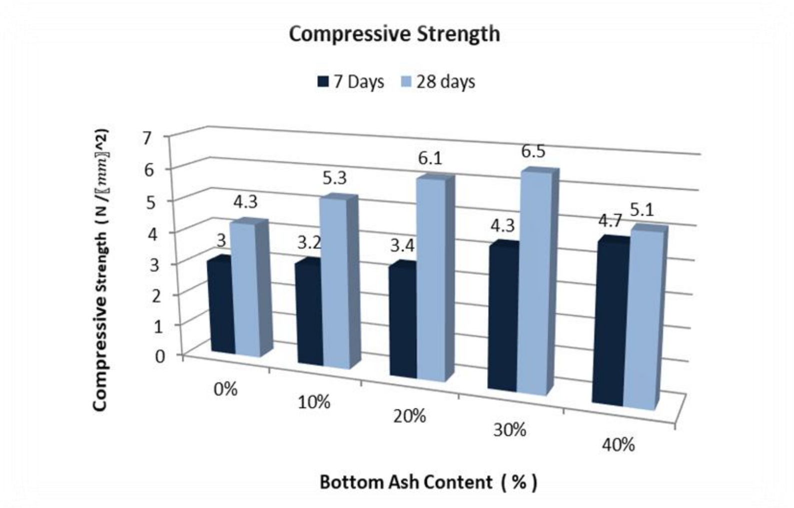

Fig. 6 Compressive strength variation in 7 to 28 days for designation (iii)

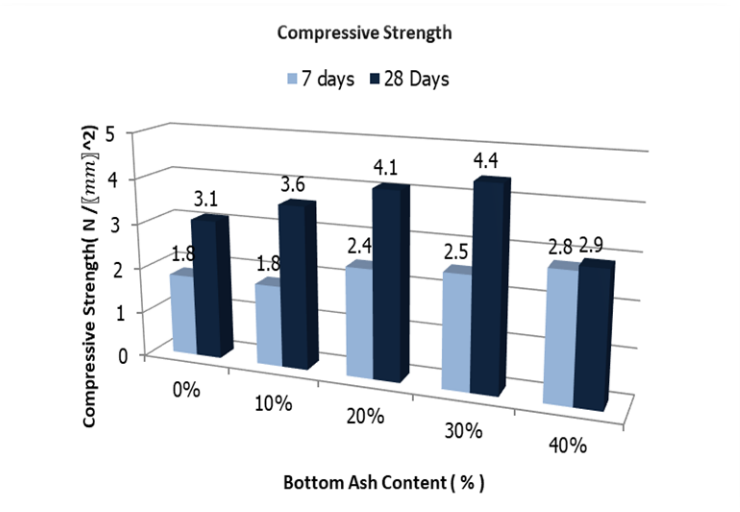

Fig. 7 Compressive strength variation in 7 to 28 days for designation (iv)

3.3 Flexural Strength of Mortar

Test results of flexural strength are given in figures 8 & 9 for designation (iii) and (iv) respectively. The highest flexural strength was gained at 30% of bottom ash replacement in both designations. The control sample gave comparatively low flexural strength than the bottom ash replaced samples. With the increment of bottom ash replacement, the flexural strength gradually increases and then suddenly drops at 40% replacement.

Compared to the control sample, the 30% bottom ash replaced samples attained the optimum flexural strength for both designations. it can be claimed that the rough surface of the open-pore aggregate grains, in combination with its high-water absorption rate enhances cooperation in the cement matrix-aggregate contact zone. Water absorbed by the aggregate grains evaporates over time which results in the phenomenon of contact area self-care, which in turn contributes to improved tensile strength (Rucinska, 2018).

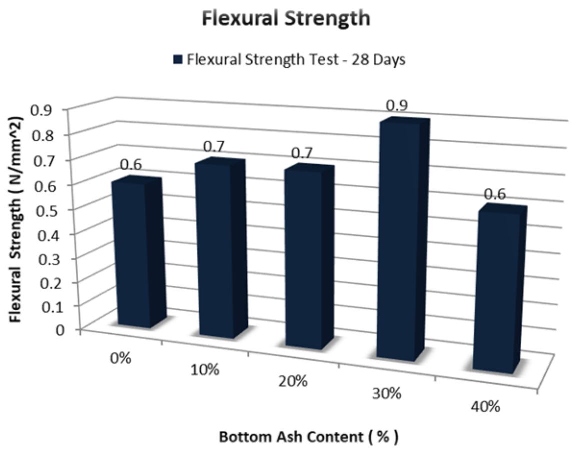

Fig. 8 Flexural strength of 1: 5 proportion at 28 days

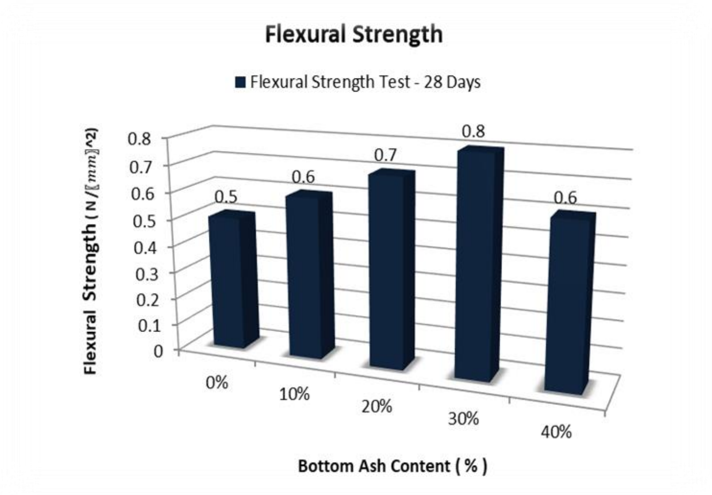

Fig. 9 Flexural strength of 1: 6 designation at 28 days

3.4 Density of Fresh and Hardened Mortar

Density variation of mortar for both designations are shown in figures 10 and figure 11. Bulk density of fresh mortar is an important parameter as it represents the ease of use. If a mortar is 'harsh', that is of poor workability and high density and hence the output of craftsmen will be reduced. Picking up and spreading will be slower and difficult in plastering. The results for both designations indicates that when increasing the amount of bottom ash replacement, the fresh bulk density and dry bulk density are reduced. Bottom ash particles are lighter than sand and are irregularly shaped (Ghosh et al., 2018). This is justified by the results of Table 1, where the specific gravity of sand is 2.68 and bottom ash is 1.52. Therefore, replacement of dense aggregate with lighter and porous aggregate will reduce the density. Hence, more the substitution percentage of bottom ash less the density.

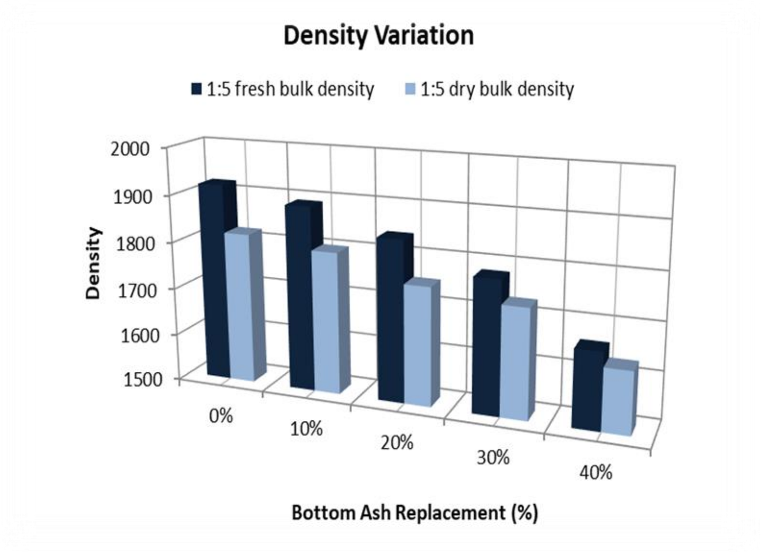

Fig. 10 Density Variation of 1:5 Proportion

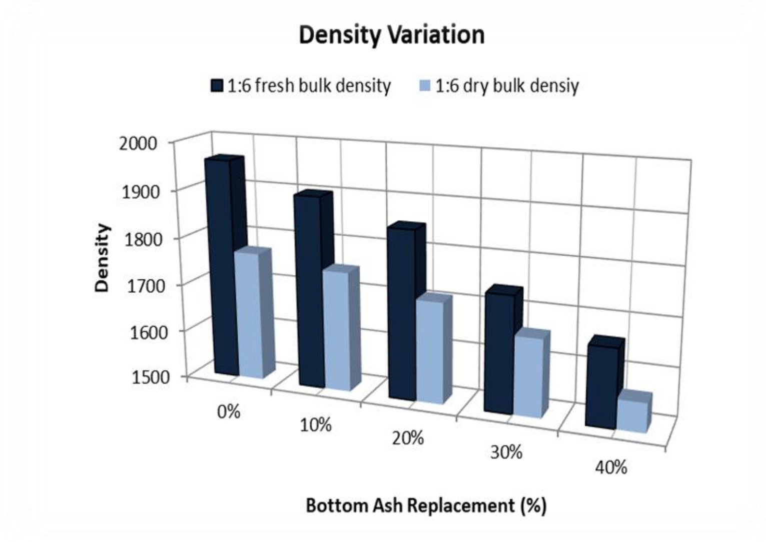

Fig. 11 Density Variation of 1:6 Proportion

3.5 Water Absorption

The results of water absorption are shown in figure 12 for both designations. Water absorption of mortar was checked 28 days after the samples were cast. The increase of bottom ash content gradually increases the water absorption of mortar up to 20% of replacement and then a slight drop at 30% and a gradual increase up to 40% was observed. Both designations show similar variation of water absorption. The bottom ash particles are porous in nature (Ghosh, et.al, 2008). This may have attributed to the increase in water absorption with the addition of bottom ash.

Generally, mortar is used for both external and internal applications. Therefore, durability of mortar is an important factor that needs consideration. The water absorption has a significant effect towards the durability. The high water absorption in mortar may result in crack failures, increase in corrosion, high shrinkage and also water based fungicidal affection. Therefore, durability of mortar depends upon water absorption. Compared to the control sample 10%, 20% and 30% replacements indicate a slight variation, Hence, from the results of water absorption, 10%, 20% and 30% bottom ash replacements can be considered to have reasonably satisfactory water absorption values to sustain the durability.

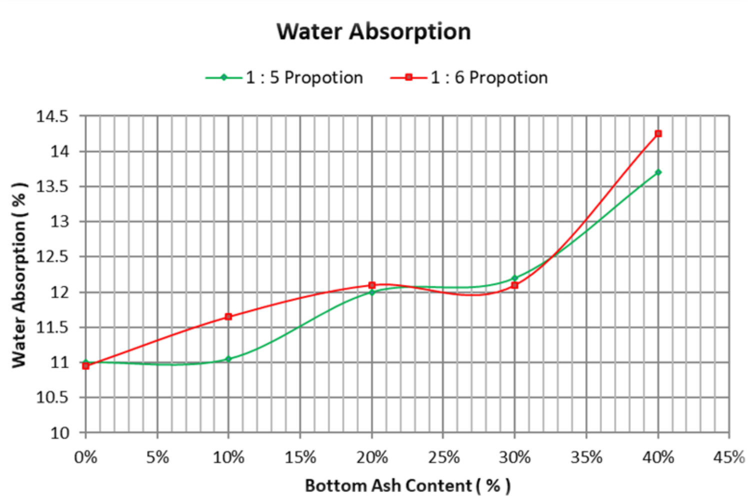

Fig. 12 Water Absorption (%) Variation of 1: 5 proportion and 1: 6 Proportion.

3.6 Application of the best composition – 30% of Bottom ash replacement

A small brick wall was plastered with identified best compositions and control samples of two designations as shown in figures 13 to 16. According to the craftsmen's experience, it was revealed that the bottom ash replaced mortar mix was easy to use. He further explained that the sliding of the plaster on the trowel is good and the paste adheres on the wall more easily than the control samples. Picking up and plastering was easier than the control sample. It is noticeable from the figures that the bottom ash replaced plasters have a smooth finish than the control samples.

Fig. 13 1: 5 plastering coat – Control mix

Fig. 14 1:5 plastering coat – 30% bottom ash replaced

Fig. 15 1: 6 plastering coat – Control mix

Fig. 16 1: 6 plastering coat – 30% bottom ash replaced

4 CONCLUSION

Bottom ash is a fine graded aggregate of low specific gravity and high-water absorption. By considering the results of hardened properties of mortar (compressive strength, flexural strength, water absorption and bulk density) and the fresh state properties (workability) the 30% of replacement of bottom ash can be selected as the optimum percentage for both mortar designations. It has also been concluded that according to the craftsmen's experience, the bottom ash replaced mortar mix was easy to use than the conventional mix.

5 ACKNOWLEDGMENT

Authors wish to express their sincere gratitude to Director. Mrs. S. Muthurathne and Mrs. Savitha Ranjan and Mr. Yohan Dissanayaka of National Building Research Organization for their guidance and support in carrying out the laboratory experiments for this study. Thanks, and gratitude is also extended to Eng. R. Bamunusinghe for providing the material bottom ash from Norochchlai power plant.

6 REFERENCES

Mahapara, A, Ravi, K and Dinesh, K, 2016. Study the effect of coal bottom ash and limestone dust as partial replacement of sand and cement. Int. J. Sci. Res. Educ. ;4(5):5363–5372.

Bahoria, B., Parbat, D. & Naganaik, P., 2013. Replacement of natural sand in concrete by waste products: A state of Art. Journal of Environmental Research and Development, 7(4A), pp. 1651 - 1655.

Bajare, D., Bumanis, G. & Upeniece, L., 2013. Coal Combustion Bottom Ash as Microfiller with Pozzolanic Properties for Traditional Concrete. Riga, Elsevier Ltd, pp. 149 – 158

Brake N. A., Oruji S, Nalluri L and Guduru, R. K, 2017. Strength activity and microstructure of blended ultra-fine coal bottom. Construct. Build. Mater.153:317–326.

Ghosh, A, Ghosh, A and Neogi, S, 2018. Reuse of flyash and bottomash in mortars with improved thermal conductivity performance for buildings. Heliyon, 4(11): E 00934

Hyeong, K.K, 2015. Utilization of sieved and ground coal bottom ash powders as a coarse binder in high-strength mortar to improve workability. Construct. Build. Mater. 91:57–64

Janardhanan, T and Venkatasubramani, R, 2015. Feasibility Studies on Compressive Strength of Ground Coal Ash Geopolymer Mortar, Periodica Polytechnica Civil Engineering 59(3), DOI: 10.3311/PPci.7696

Kumar, D., Gupta, A. & Ram, S., 2014. Uses of Bottom ash in the Replacement of fine aggregate for Making Concrete. International Journal of Current Engineering and Technology, 4(6), pp. 3891- 3895.

Ranjan, S. & Nanayakkara, S.M.A., 2013. Development of light weight building blocks using bottom ash from coal fired thermal power plants. In Annual NBRO Symposium on Engineering in Disaster Resilience. Colombo, 2013. University of Moratuwa.

Rucinska, T, 2018. Sustainable Mortars, VII Conference of SOLINA Sustainable Development: Architecture - Building Construction - Environmental Engineering and Protection Innovative Energy-Efficient Technologies - Utilization of Renewable Energy Source, https://doi.org/10.1051/e3sconf/20184900

Shahiron., S, Nurul, R.R.I, Mohamad, M.Z and Noorwirdawati, A, 2016. Physical and chemical properties of Coal Bottom Ash (CBA) from Tanjung Bin Power Plant, International Engineering Research and Innovation Symposium (IRIS) IOP Conf. Series Mater. Sci. Eng. 160 012056