# DEVELOPMENT OF LIGHT WEIGHT CEMENT BLOCKS WITH BOTTOM ASH FROM COAL FIRED THERMAL POWER PLANTS


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# Abstract

In the Nuraicholai coal fired thermal power plant, 7500 MT of coal per day is burnt producing 750 MT and 75 MT of two main waste products fly ash and bottom ash respectively. Fly ash is used in cement manufacture, but bottom ash is presently regarded as a waste material. However, there is a possibility to convert bottom ash to a value added material. This thesis presents findings pertaining to the feasibility of using bottom ash as a replacement of sand in producing light weight cement blocks. Chemical analysis carried out using Atomic Absorption Spectroscopy on Nuraicholai power plant bottom ash waste showed that the harmful elements present such as As, Pb, Cr, Cd, Cu, Ni and Se were within internationally specified toxicity limits for soil. It was found that bottom ash at oven dry condition had a loose bulk density of 600 kg/m$^3$, which is about 40% that of river sand which has a nominal loose bulk density of about 1450 kg/m$^3$. Important physical and mechanical properties such as compressive strength, water absorption, density, accelerated erosion resistance and drying shrinkage & wetting expansion were tested for blocks produced by partly or fully replacing fine aggregate with bottom ash. Heat conductivity of blocks produced with bottom ash was found to be less than the good quality conventional cement blocks available in Sri Lanka. Comparatively, performance of the bottom ash blocks was very good and comparable with conventional cement blocks produced with river sand and quarry dust. Further, trials were carried out with river sand, crushed rock sand and coarse aggregate in order to find out optimum mix proportions and to investigate the feasibility of medium scale production of bottom ash blocks using a conventional type of block making machine. The optimum mixes which give strength, density and water absorption of desirable amount were found with Cement, Quarry dust, Bottom ash and 5-10 mm crushed rock aggregates.



**Keywords:** Bottom ash, fine aggregate, crushed rock aggregate, light weight cement blocks

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# CHAPTER 1

# 1. INTRODUCTION

## 1.1 Need for Research

Coal combustion is a popular choice to produce electricity worldwide. The two main waste products coming from coal fired power plants are fly ash and bottom ash. Disposal of waste produced from the thermal power plant requires proper handling to overcome environmental effects caused by such material. The Lakvijaya Power Station (also known as the Nuraicholai Power Station after its location) is a large coal-fired power station in Nuraicholai, Puttalam, Sri Lanka. In the Nuraicholai coal fired thermal power plant, 7500MT of coal is burnt per day when the plant is running at its full capacity to generate 900 MW and it produces 750 MT of fly ash and 75 MT of bottom ash per day. Although fly ash could be gainfully utilized in cement manufacture, bottom ash is presently regarded as a waste material.

At present, bottom ash is not used in any useful application. Therefore, disposing of bottom ash is a problem. This material is presently piled up in a large dumping area causing air and water pollution. However, this environmental problem may be overcome if bottom ash could be utilized as a substitute for river sand or crushed rock sand in the manufacture of cement blocks. This is possible because bottom ash has a high content of silica (>95%) as in river sand.



In Sri Lanka, bricks and blocks are the most commonly used material for wall construction. These are conventional material and there have been very little development in terms of new building bricks or blocks. Both bricks and blocks have been designed for easy handling in terms of size and weight. In Sri Lanka, there are three types of cement blocks are in use. They are solid, cellular and hollow blocks. Size of a block with normal weight aggregate is limited because of this handling problem due to its weight. Commonly used standard cement block sizes in Sri Lanka are, 390mm x 200mm x 190mm, 390mm x 150mm x 190mm and 390mm x 100mm x 190mm. These blocks are used for wall construction. Paving blocks are only solid blocks, becoming more common.

Important properties of cement blocks are strength, absorption, density and dimensional stability (drying shrinkage and wetting expansion). Requirements for the above properties are specified in Sri Lanka Standard (SLS 855-1: 1989). Thermal properties are not specified in this standard. Light weight block with larger size will be useful for masonry construction because it will increase the labour efficiency/input in construction, reduce mortar joints and reduce the number of blocks per unit area.

Published literature indicates that other countries have successfully used bottom ash for several applications such as filling material, pavement bases, building block making and paving block making (Bai & Basheer 2001; Geetha & Ramamurthy 2011; Kim & Lee 2011; Nisnevich & Eshel 2001; Pavlenco, Malyshkin & Tkachenko 2001).

Because of the light weight properties of bottom ash, it has a potential to produce light weight block especially in view of its low particle density, granular structure and mineral composition. Manufacturing light weight cement blocks using bottom ash aggregate ensures a utilization of waste from coal fired power plant and can solve persistent environmental and economical problems as follows;



i. avoiding leaching of heavy metals from bottom ash stock piles
ii. removal of waste piles, thus conserving land for more productive uses
iii. conservation of natural resources by reducing the consumption of river sand
iv. Reduction in production cost of cement blocks
v. In designing a building, section size of structural members can be reduced due to lighter dead load due to light weight blocks

Dumping of coal bottom ash as a waste material at the rate of 75MT per day has given rise to serious environmental problems and need to address the following issues:

- Arresting environmental pollution of land, ground water and water ways or even air pollution.
- Devising methods of economic utilization of coal bottom ash

Apart from the problems which are of recent origin, the construction industry has been facing the problem of adverse effects of excessive mining of river sand over a long period of time. Control measures introduced to overcome these environmental effects have resulted in an acute scarcity, escalation of prices and poor quality of river sand available for the use in the construction industry and in the manufacture of cement based products such as sand-cement blocks.

The problem of environmental pollution caused by the dumping of coal bottom ash could be overcome by making effective use of this material, if possible with some value addition.

Some of the important research objectives set out to implement the National Science and Technology Policy of Sri Lanka are,

- Disseminating the benefits of S&T activities to all sectors
- Improved environmental quality
- Utilization of industrial wastes
- Improved construction quality



This research was carried out at National Building Research Organization (NBRO) which launched its research programme to achieve these objectives. Bottom ash has been piling up around the Lakvijaya power plant in Nuraicholai polluting hundreds of acres of land. It contains toxic metals such as arsenic, lead and Cadmium.

Although the toxicity levels are not very high to be considered as hazardous, the material is yet environmentally unfriendly and likely to pollute the ground water if it is allowed to accumulate without control. Presently, it could be used as a material for land filling but this usage will not alleviate the environmental problem to a sufficient level. Moreover, there is no value addition to the material when used as a fill material. This research has not only addressed these issues, but has also been successful in addressing the environmental issues arising from excessive mining from river sand, because bottom ash can be used as a replacement to river sand.

## 1.2 Objective of the Study

Although the literature review showed that there have been many research studies regarding the utilization of bottom ash, studies related to use of bottom ash in Sri Lanka were not available.

Materials used for the manufacture of cement blocks and clay bricks are sand, cement and clay. Extraction of clay and sand causes environmental problems. The new trend in block manufacture is to replace river sand with crushed rock sand. However, rock quarrying/ crushing also causes environmental problems. Therefore, replacement of both river sand and crushed rock sand with a more eco-friendly material will be beneficial.

The main objective of this research was to investigate the possibility of utilizing bottom ash from coal fired power plants to produce light weight blocks for building construction because it will give rise to economic benefits in construction, and it could also reduce the demand for river sand and quarry dust in block production.

In order to meet the main objective of the research, the following methodology was adopted.



1. Literature survey
2. Experimental investigation of properties of bottom ash
3. Determination of suitable mix proportions for cement mortar blocks made of bottom ash
4. Determination of physical, mechanical, and thermal properties of bottom ash cement mortar blocks
5. Cost analysis of production of cement mortar blocks with bottom ash

Nuraicholai Power Plant was started to meet the energy requirement of Sri Lanka. However environmental pollution due to dusty waste materials has been occurring, therefore, there is a need for research on waste management. At the same time, there is a huge demand of building blocks in the Sri Lankan construction sector. Therefore, the solution offered by this research project will be very useful, leading to the manufacture of cost effective, light weight blocks using bottom ash as a replacement of river sand or crushed rock sand.

Research study was focused to producing building blocks to satisfy the requirements specified in SLS 855-1:1989 with minimum characteristic compressive strength of 2 N/mm$^2$. To supplement the work described in the methodology a study on present cement block making techniques, methods and materials used (by circulating a questionnaire to block manufacturers and by visiting industries of interest) was also carried out.

**1.3 Guide to Thesis**

Chapter 1 describes need and objective of this research.

Chapter 2 describes literature survey carried out on coal fired power plants, by-products of coal fired power plants and their ways of extraction, physical, thermal and chemical properties of bottom ash, bottom ash applications in the world, possibility of making blocks using bottom ash, radioactive elements in bottom ash.

Chapter 3 describes research methodology, experimental investigation on properties of bottom ash and bottom ash blocks, survey on block production and sampling of bottom ash.



Chapter 4 describes test results obtained for properties of bottom ash, properties of blocks produced with Cinva-Ram machine and properties of blocks produced with conventional cement block making machine.

Chapter 5 describes cost analysis of bottom ash blocks which satisfied strength and absorption requirements.

Chapter 6 describes conclusions and recommendations of this research study.

# CHAPTER 2

# 2. LITERATURE REVIEW

## 2.1 Coal Fired Power Plants

In Sri Lanka, oil fired thermal power plants were first constructed to meet the ever increasing demand for electricity. In view of their high cost of production and adverse environmental effects, the authorities decided to set up coal fired power plants. However, the amount of waste produced from a coal-fired power plant is high and proper handling and disposal systems are needed. The production of coal ashes and the environmental problem which arises from them has prompted various studies on the utilization of ash, contemplating on producing value added material with these wastes.

### 2.1.1 Coal

At the Lakvijaya Power Station (Fig.2-1), coal is imported from Indonesia since it is cheap and is of good quality. Even though the coal in India is comparatively cheap, Indonesian coal is used since the coal in India contains more sulfur (Institute of Engineers Sri Lanka 2013). As per the conversation with the authorities of the power plant, coal is imported from South Africa too. However, at the time of sampling, coal used was from Indonesia.




Figure 2-1: Nuraicholai coal power plant

Coal (from the Old English term col), which means "mineral of fossilized carbon" is a combustible black or brownish-black sedimentary rock mainly of carbonized plant matter, found to produce energy in the form of heat. It is composed primarily of carbon along with variable quantities of other elements, mainly hydrogen, sulfur, oxygen and nitrogen, as well as small quantities of aluminium, Zirconium and many other metals. Silica is present in ash of coal. When coal is fired, trace elements such as As, Sb, Cd, Cr, Pb, Ni, Se, Ti and Zn occur in particles of bottom ash and fly ash.

### 2.1.2 Coal ashes as by-products

Fly ash and bottom ash are the two main waste products in coal firing thermal power plants. Dust in emissions from the furnace is fly ash and it is separated from gaseous emissions released to atmosphere from stacks. Dust collected at the bottom of the furnace is known as bottom ash and it is conveyed to a hopper and collected ash is removed periodically to waste disposal areas.

#### 2.1.2.1 Fly ash



Fly ash is in the form of very fine spherical particles that escape with the hot emission gases leaving the furnace. Fly ash is primarily composed of valuable industrial minerals such as alumina, silica, lime and iron oxide. Greater concentrations of these elements are in fly ash compared to bottom ash (Kim & Lee, 2011). Furthermore, very fine particles in fly ash are highly reactive. Therefore, fly ash has a high demand for use in cement production as a supplementary cementitious material for producing blended cement. Table 2-1 shows the types of common cements which contain fly ash as a supplementary cementitious material.

Fly ash has specific gravity in the range of 2.20 and fineness 400.0 $m^2/kg$ when measured using Blaine's method. Chemical analysis on fly ash showed that it contains varying amounts of Silicon dioxide ($SiO_2$), Aluminum oxide ($Al_2O_3$), Ferric oxide ($Fe_2O_3$), Calcium oxide (CaO), Magnesium oxide (MgO), Sulfur trioxide ($SO_3$), Sodium oxide ($Na_2O$) and Potassium oxide ($K_2O$) for difference sources. Fly ash also contains trace elements such as mercury, arsenic, antimony, chromium, selenium, lead, cadmium, nickel, and zinc (Nisnevich & Eshel 2001 ; Sandra 2009).

Table 2-1: Fly ash in common cements

| Main Type | Types of common cement | | Composition (Percentage by mass) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Main Constituents | | | | | | | | | | Minor additional constituents |
| | | | Clinker | Blast Furnace Slag | Silica Fume | Pozzolana: Natural | Pozzolana: Natural calcined | Fly Ash: Siliceous | Fly Ash: Calcareous | Burnt Shale | Limestone: L | Limestone: LL | |
| CEM II | Portland fly ash cement | CEM 11 A-V | 80-94 | - | - | - | - | 6-20 | - | - | - | - | 0-5 |
| | | CEM 11 B-V | 65-79 | - | - | - | - | 21-35 | | | | | 0-5 |
| | | CEM 11 A-W | 80-94 | - | - | - | - | - | 6-20 | - | - | - | 0-5 |
| | | CEM 11 B-W | 65-79 | - | - | - | - | - | 21-35 | - | - | - | 0-5 |
| | Portland composite cement | CEM 11 A-M | 80-94 | ← 6 to 20 → | | | | | | | | | 0-5 |
| | | CEM 11 B-M | 65-79 | ← 21 to 35 → | | | | | | | | | 0-5 |
| CEM IV | Pozzolanic cement | CEM IV/A | 65-89 | - | ← 11 to 35 → | | | | | - | - | - | 0-5 |
| | | CEM 1V/B | 45-64 | - | ← 36 to 55 → | | | | | - | - | - | 0-5 |
| CEM V | Composite cement | CEM V/A | 40-64 | 18-30 | - | ← 18 to 30 → | | | - | - | - | - | 0-5 |
| | | CEM V/B | 20-38 | 31-50 | - | ← 31 to 50 → | | | - | - | - | - | 0-5 |

Source: BS EN 197: 2000

Figure 2-2 shows the SEM image of fly ash in which round particles can be observed.

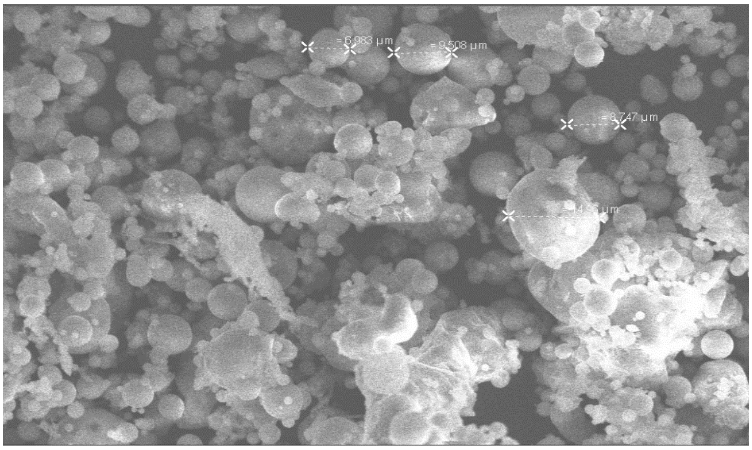

Figure 2-2: SEM image of fly ash

As per the American Standard there are two classes of fly ash. They are F and C. The F class fly ash has pozzolanic properties whereas the C class fly ash has both pozzolanic and cementitious properties (ASTM C 618 : 2012). When fly ash is used in concrete, the heat of hydration will be reduced and the long term strength will be increased, but the early stage strength will be reduced. Therefore, in mix design, testing at 56 days is acceptable. Other benefits are: expansion due to alkali-silica reaction will be reduced, workability is improved, setting time will be extended and water permeability will be reduced. However, there are some disadvantages of using fly ash in concrete such as the resistance to carbonation will be reduced. Therefore, adequate curing is important and cover requirements should be ensured (Thomas 2007).



2.1.2.2 Bottom ash

Bottom ash is composed of heavier particles with a coarse granular composition that are collected from grates beneath the furnace. Bottom ash is also primarily composed of valuable industrial minerals such as alumina, silica, lime and iron oxide, but in lesser concentrations as compared to fly ash.

### 2.1.3 Extraction of bottom ash

Three types of methods are commonly used in thermal power plants to extract bottom ash (See Table 2-2). Nuraicholai thermal power plant uses jet pumps to extract bottom ash in slurry form (see Figure 2-3). This slurry is then transferred to a storage area.

If fly ash is not totally extracted separately, the bottom ash that is sluiced to the storage area will usually be combined with fly ash.

Table 2-2: Method of removal of bottom ash output

| Method | Form of bottom ash output | Advantages | Disadvantages |
|---|---|---|---|
| Using jet pumps | Slurry | Reduce high heat to environment, Reduce dust formation, Less space | Water requirement is high, Involves lot of piping and valves |
| Using scraper chain conveyor and belt conveyor | Dry | Simple, Less water requirement | Space requirement is high, Good quality chains are required |
| Using air cooling system | Dry | No water usage Clean system | High cost |



Note: Information given in this table was provided by Eng. Indika of Nuraicholai power plant on 14th March 2013.

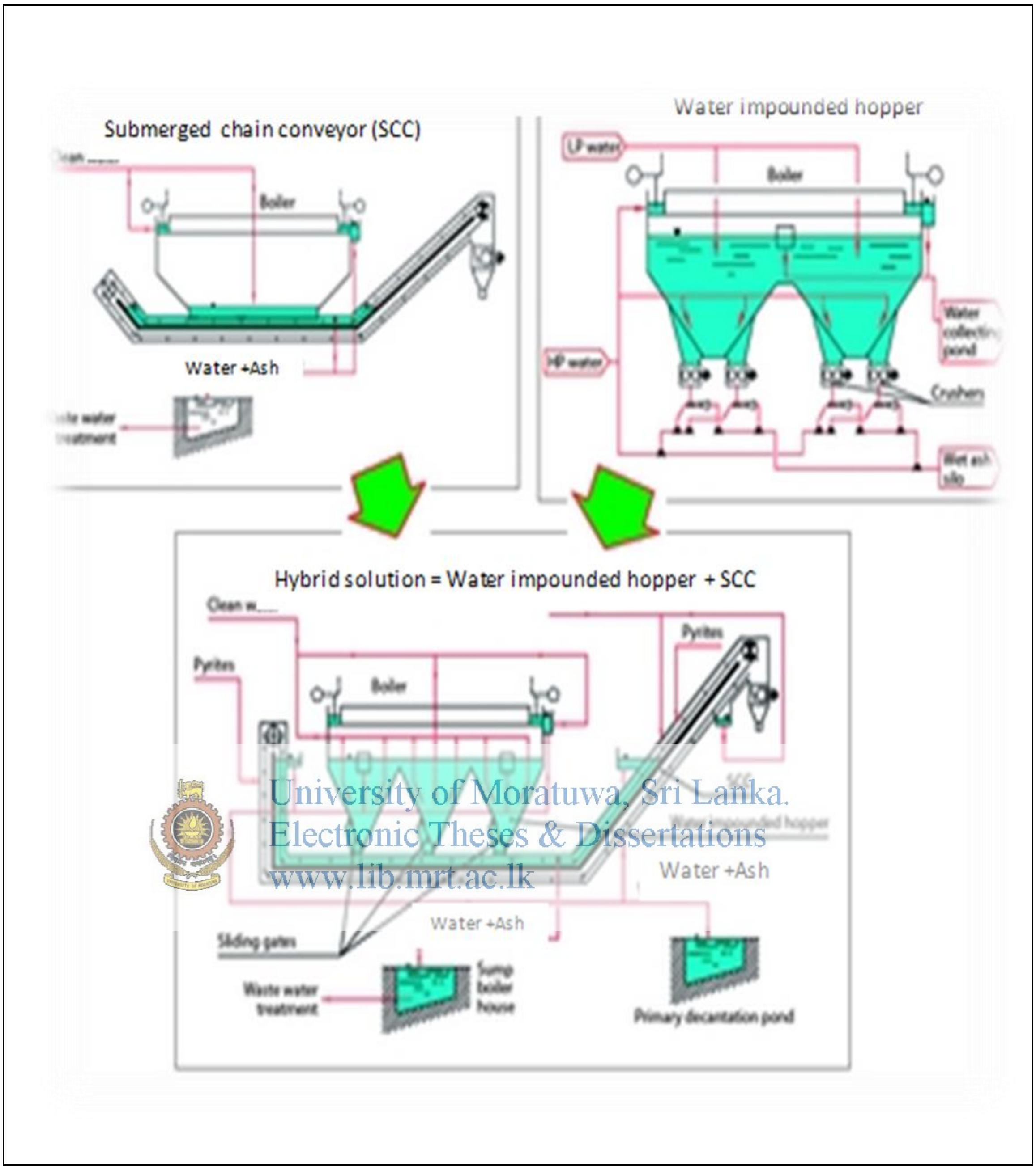




Figure 2-3: Extraction of Bottom ash

Source: *Coal Bottom Ash/ Boiler Slag Material,2012*(RMRC-3G 2012)

## 2.2 Properties of Bottom Ash

### 2.2.1 Physical properties

According to Bai & Basheer, 2001 Bottom ash has angular particles with very porous surface textures. It is incombustible. The ash particles range in size from a fine gravel to a fine sand with very low percentages of silt-clay sized particles. Bottom ash is predominantly sand-sized, usually with 50 to 90 percent passing 4.75 mm sieve and 0 to 10 percent passing 0.075 mm sieve.

The largest bottom ash particle sizes typically range from 19 mm to 38 mm. Bottom ash is usually a well-graded material although variations in particle size distribution may be encountered in ash from the same power plant. Density of bottom ash is in the range of 750kg/m$^3$. According to BS EN 13055-1:2002, it falls under the category of light weight aggregate since the density is less than 1000 kg/m$^3$. Figure 2-4 shows particle size distribution of some bottom ash samples in different power plants in the US. It can be seen that most of the samples have particle size of less than 10 mm.



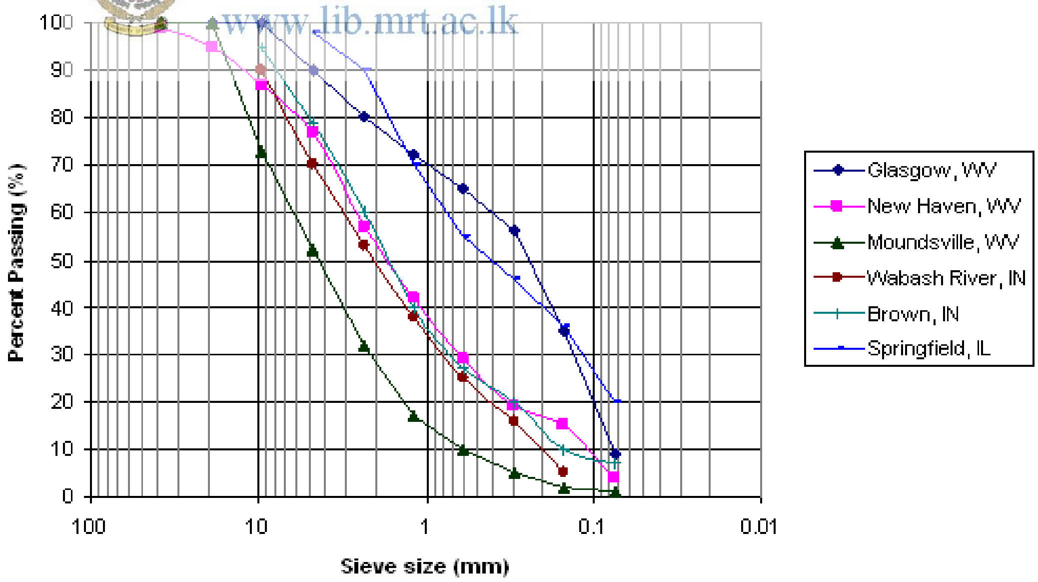


Figure 2-4: Particle size distribution of bottom ash samples

Source: *Coal Bottom Ash/ Boiler Slag Material,2012*(RMRC-3G 2012)

### 2.2.2 Chemical composition and trace elements

The major chemical components of bottom ash are the same as fly ash; however, due to the larger particle size and lower specific surface area, bottom ash has a lower potential to leach trace elements than fly ash when used in the same application.

Due to the variability in bottom ash composition between coal plants, industry-wide generalizations about the environmental impact of bottom ash cannot be made (Baba & Kaya 2004; Lee & Taeyon 2011). Therefore, leachability of heavy metals from bottom ash obtained from Lakvijaya power station also should be determined from time to time. Chemical composition of bottom ash and types of bottom ash as per its chemical composition are given in Table 2-3. Table 2-3 &2-4 show categorization of bottom ash as per their main or trace elements constituents. Table 2-5 shows usual range of trace elements constituents in coal and ashes.

Table 2-3: Types as per composition of bottom ashes



| Composition | Composition as a percentage (%) | | |
|---|---|---|---|
| | Lignite | Sub-bituminous | Bituminous |
| $SiO_2$ | 10.80-48.30 | 45.3 | 48.81-58.9 |
| $Al_2O_3$ | 2.50-24.90 | 24.0 | 10.12-36.0 |
| $Fe_2O_3$ | 0.50-8.20 | 18.0 | 2.4-6.10 |
| MgO | 0.40-4.60 | 0.58 | 0.2-5.61 |
| CaO | 8.60-45.10 | 1.4 | 1.3-11.81 |
| $Na_2O$ | 0.15-1.15 | 0.45 | 0.04-0.92 |
| $K_2O$ | 0.02-3.60 | 0.53 | 0.6-2.31 |
| $TiO_2$ | 0.18-1.32 | 1.5 | 0.39-0.60 |
| $P_2O_5$ | - | 2.2 | 0.02-0.79 |
| MnO | 0.03-0.21 | 0.05 | 0.02-0.08 |
| $SO_3$ | 5.10-20.20 | 2.2 | <0.1-4.06 |
| S | 0.1 | 0.2-0.3 | 0.01 |
| LOI | 4.6 | 9-17.8 | 9.75 |

Source: Jayaranjan, Hullebusch& Annachhatre 2014

Table 2-4 : Trace elements in bottom ash

| Trace elements | Trace element composition of bottom ash (mg $kg^{-1}$ dry basis) | | |
|---|---|---|---|
| | Lignite | Sub-bituminous | Bituminous |
| As | - | 25-30 | 1.8 |
| B | - | 321-467 | 15.30 |
| Ba | 62-109 | 428-523 | - |
| Cd | <5 | 0.5-0.6 | 0.3 |
| Co | 3-7 | 10-13 | 17.5 |
| Cr | 47-194 | 65-99 | 47 |
| Cu | 18-121 | 33-49 | 32 |
| Hg | 0.4-1.6 | - | - |
| Li | 4.30 | 93-147 | 28 |
| Mn | 97-328 | 295-402 | 991 |
| Ni | 30-293 | 34-53 | 30 |
| Pb | 5-33 | 16-29 | 2.6 |
| Zn | 33-226 | 59-99 | 47 |

Source: Jayaranjan, Hullebusch & Annachhatre 2014

Table 2-5: Trace elements concentration

| Element | Concentration (mg/kg) | | | | |
|---|---|---|---|---|---|
| | Fly ash | Bottom ash | FGD material | Coal | Soil |
| As | 2-1385 | 0.02-168 | 0.8-386 | 0.5-106 | 1-50 |
| B | 10-5000 | 2-513 | 42-948 | 1.2-365 | 2-100 |
| Ba | 1-13800 | 110-9360 | 25-2280 | 150 | 100-3000 |
| Cd | 0.1-130 | 0.1-4.7 | 0.06-40.7 | 0.1-6.5 | 0.1-0.7 |
| Cr | 4-900 | 0.2-5820 | 2-180 | N.D-610 | 1-1000 |
| Cu | 19-2200 | 4-930 | 6-1490 | 1.8-185 | 2-100 |
| Hg | 0.01-12 | 0.01-6 | 0.01-6 | 0.01-1.6 | N.D |
| Mn | 25-3000 | 56-1940 | 40-625 | 6-181 | 20-3000 |
| Mo | 1-236 | 1-443 | N.D-63.7 | N.D-73 | 0.2-5 |
| Ni | 1.9-4300 | 10-2900 | N.D-156 | 0.4-104 | 5-500 |
| Pb | 3-2120 | 0.4-1100 | 0.3-300 | 4-218 | 2-200 |
| Se | 0.2-130 | 0.1-10 | N.D-160 | 0.4-8 | 0.1-2 |
| Sr | 30-7600 | 170-6440 | 70-3170 | 100 | 50-1000 |
| Ti | 1310-10100 | 1540-13000 | - | 20-3200 | 1000-10000 |
| V | 12-1180 | 12-540 | N.D-260 | N.D-1280 | 20-50 |
| Zn | 14-3500 | 4-1800 | 8-610 | N.D-5600 | 10-300 |

Source: Jayaranjan, Hullebusch & Annachhatre 2014

### 2.3 Bottom Ash Usage in the World

The quality and amount of bottom ash depends on the quality of coal burnt and type of furnace used to burn the coal. When coal is burnt in a boiler, 10% of ash is dry bottom ash and 90% is captured and recovered as fly ash. These amounts vary 20% and 80% respectively for bottom and fly ash as per the studies in different countries (Beretka & Mathew 1985; Nisnevich & Eshel 2001).

Currently bottom ash is used for various applications in the world, such as snow and ice control, production of cement, road bases and subbases, structural fill material and as an aggregate in light weight concrete and masonry units. Over the past few decades, regulatory guidelines for recycling of coal combustion byproducts have been developed. As per the US EPA website (Environmental Protection Agency 2015), they conducted two regulatory determinations on the management and use of coal combustion byproducts in 1993 and in 2000.

Upon conducting these assessments, the EPA did not identify environmental hazards associated with the beneficial use of coal combustion products and concluded these materials did not warrant regulation as hazardous wastes. In May 2000, the EPA made the statement, "we do not wish to place any unnecessary barriers on the beneficial use of fossil fuel combustion wastes so that they can be used in applications that conserve natural resources and reduce disposal costs." This includes the beneficial use of coal combustion products in both encapsulated and unencapsulated transportation applications. The EPA recognizes that unencapsulated uses of coal combustion byproducts require proper hydrogeological evaluation to ensure adequate groundwater protection.

### 2.3.1 Use of bottom ash as a raw material in cement production

Figure 2-5 shows that more than 50% of bottom ash produced in the world is used in manufacturing of cement (RMRC-3G 2012).

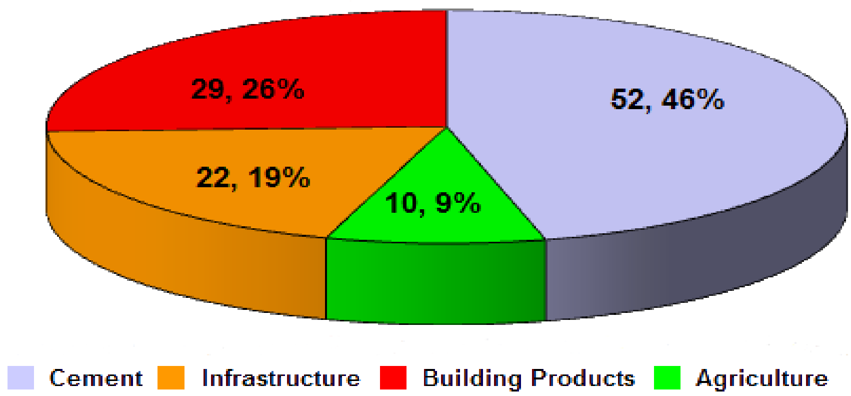


Figure 2-5: Bottom ash uses (in thousands tons) in 2012

Source: *Coal Bottom Ash/ Boiler Slag Material,2012*(RMRC-3G 2012))

### 2.3.2 Use as a structural fill material



Figure 2-6 shows that typical applications of bottom ash in the U.S. in 2006.

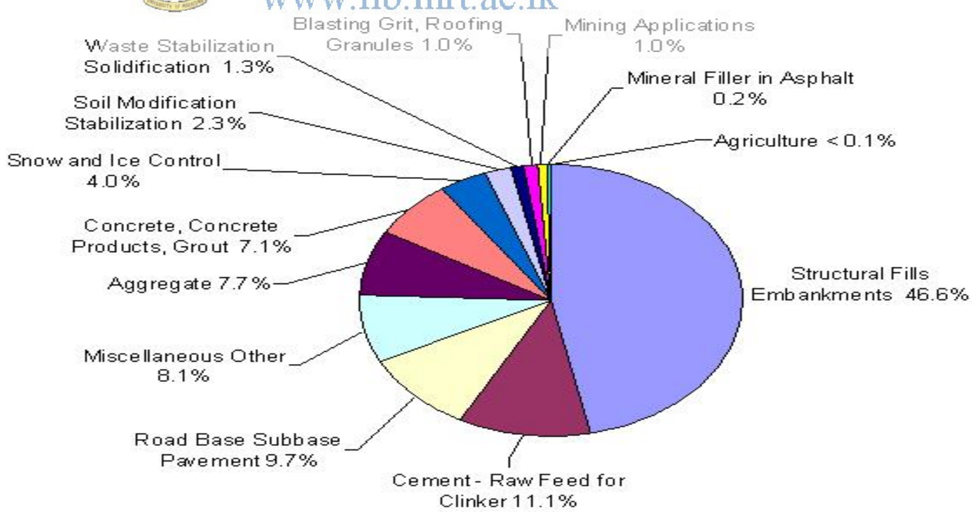


Figure 2-6: Bottom ash applications as a percentage of totals reused in the U.S. in 2006

Source: *Coal Bottom Ash/ Boiler Slag Material,2012*(RMRC-3G 2012)

At many construction sites, large quantities of fill materials are frequently required to level low places for construction and drainage purposes, build embankments, fill trenches, backfill foundations, etc. According to the reference (RMRC-3G 2012) bottom ash is commonly used in these applications in U.S. if it is available and close enough to be transported economically. However, the possibility of groundwater contamination by trace elements that are commonly associated with coal combustion by-products is a concern.

### 2.3.3 Applications of bottom ash in concrete

Applicability of an industrial bottom ash, supplied from Tunçbilek Power Station-Turkey, in concrete industry was evaluated by Baba and Kaya ( Baba & Kaya 2004). In the laboratory experiments, the bottom ash was used up to 25% as a partial substitute for the Portland cement. Based on the obtained results, it was concluded that the addition of bottom ash up to 10% as a replacement material for Portland cement could improve the mechanical properties of concrete, and thus, could be used in the concrete industry ( Baba & Kaya 2004).



Bottom ash is a light weight material. The density of hardened concrete linearly decreases as the replacement of aggregate with bottom or fly ash and compressive strength was not strongly affected by the replacement of fine aggregate with bottom ash (Kim and Lee 2011). Also Kim and Lee found that flexural strength of concrete almost linearly decreased as the replacement ratio of bottom ash was increased. The modulus of rupture was decreased, since the cracks caused by flexural load easily propagated through bottom ash particles while the normal aggregates were hard to penetrate, and consequently the direction of the crack propagation was changed by the normal aggregate. Therefore, producing high strength concrete with 100% replacement of fine aggregate with bottom ash is not possible.

Studies on bottom ash also showed that low density, low thermal conductivity, low shrinkage and high heat resistance concrete could be achieved with the replacement of fine aggregate with bottom ash (Nisnevich & Eshel 2001).

### 2.3.4 Road construction applications

Blended fly ash and bottom ash is referred to as ponded ash. Ponded ash has been used in stabilized base or subbase mixes and in embankment construction. However, in the Nuraicholai coal fired power plant, fly ash is extracted separately and sold to cement companies to produce blended cement or use as a supplementary cementitious material (SCM) in concrete production. Therefore, the bottom ash that is piled separately hardly contains any fly ash.

The U.S. Environmental Protection Agency (EPA) has delegated responsibility in the U.S. to the states to ensure that coal combustion by-products are properly used. In the U.S., Bottom ash has been used as fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, and in emulsified asphalt cold mix wearing surfaces and base courses. Bottom ash is more commonly used in base courses than wearing surfaces. Laboratory research carried out in the U.S. has shown that hot mix asphalt with up to 15 percent bottom ash had comparable performance to control mixes, therefore cost effective and helps in waste management (Environmental Protection Agency 2015).



Bottom ash has also been used in stabilized base applications. Stabilized base or subbase mixtures contain a blend of aggregates and cementitious materials that bind the aggregates to increase bearing strength. Types of cementitious materials typically used include Portland cement, cement kiln dust, or pozzolans with activators, such as lime, cement kiln dusts, and lime kiln dusts. These cementitious properties have been found in coal bottom ash, which make it attractive options for stabilized base. The pozzolanic or cement-like activity of this material, which contributes to the time-dependent change in mechanical properties, can be controlled by adjusting the particle size through sieving only or grinding and sieving (Bai & Basheer 2001).

### 2.3.5 Pavement construction

Bottom ash has occasionally been used as unbound aggregate or granular base material for pavement construction. Bottom ash is considered as fine aggregates in this application. To meet required specifications, the bottom ash may need to be blended with other natural aggregates prior to use as a base or subbase material. Screening or grinding may also be necessary particularly for the bottom ash, where large particle sizes greater than 19mm are present in the ash (Bai & Basheer 2001).

## 2.4 Possibility of Using Bottom Ash in Cement Block Making

In India, main power generation is coal-based and utilization of bottom ash is a challenge. Tata power installed and commissioned a bottom ash brick-making pilot plant. The bricks are being manufactured in a very eco-friendly manner and are being used to make walkways, road paving and internal walls. Bottom ash was used for landscaping areas within the premises. They used 400 kg of bottom ash and 500 kg of fly ash per day to produce 250 bricks (www.tatapower.com, 06.07.2012).



## 2.5 Studies on Natural Radiation in Bottom Ash

As a general view, application of coal combustion ashes in building materials has been limited by the presence of minor components that are hazardous, such as radioactive substances, chlorinated dioxins and heavy metals, or have a negative impact on product quality or production economics, such as phosphate, fluoride, carbon and chloride (Quindos et al. 2004). Therefore, it is necessary to study those effect in bottom ash thoroughly before put into use. Previous studies on using bottom ash as a replacing material for fine aggregate in concrete also showed that concrete could be manufactured in compliance simultaneously with good density and compressive strength. It is established that lightweight concrete with highly porous bottom ash as aggregate and high volume of fly ash, is a potential structural material, possessing the optimum correlation between the desirable properties: sufficiently high strength and essentially low density (Nisnevich & Eshel 2001).

As per U.S. Environmental Protection Agency 2012 radiation of bottom ash is less than that of fly ash.

All materials naturally have certain amount of radiation. Therefore, human beings have always been exposed to natural radiations arising from within and outside the earth. The exposure to ionizing radiations from natural sources occurs because of the naturally occurring radioactive elements in the soil and rocks, cosmic rays entering the earth's atmosphere from outer space and the internal exposure from radioactive elements through food, water and air. Natural radioactivity is wide spread in the earth's environment and it exists in various geological formations in soil, rocks, plants, water and air. The natural radioactivity of soil sample is usually determined from the Ra-226, Th-232, and K-40 contents (Singh et al. 2004).

The distribution of Ra-226, Th-232 and K-40 in soil is not uniform. Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity ($Ra_{eq}$) in Bq/kg to compare the specific activity of materials containing different amount of Ra-226, Th-232 and K-40. It is calculated through the following relation.



$$Ra_{eq} = C_{Ra} + 1.43\, C_{Th} + 0.07 C_{K}$$

Where "C" denote activity concentrations (Singh, Rani and Mahajan 2004).

OECD, (the Organization for Economic Co-operation and Development) which is for social security, economic, social and environmental change for countries include Australia, Canada, Denmark, India, Hong Kong, China, Indonesia, Italy, Japan, Pakistan, Saudi Arabia, Thailand and US etc. set the limit for radiation activity as 370Bq $kg^{-1}$(Singh, Rani and Mahajan 2004).

Following equations and formulae are used to calculate Radiation equivalent value for soil or relevant materials (Singh, Rani and Mahajan 2004).

1. Radium Equivalent Activity ($Ra_{eq}$)

$$Ra_{eq} = C(Ra) + 1.43C(Th) + 0.077C(K) \text{------------Eq .1}$$

2. Criteria Formula

$$\frac{C_{Ra}}{740Bq/kg} + \frac{C_{Th}}{520Bq/kg} + \frac{C_K}{9620Bq/kg} \leq 1 \text{-------- Eq.2}$$

Where C(Ra), C(Th) and C(K) are the activities of $^{226}$Ra, $^{232}$Th and $^{40}$K respectively, in Bq $kg^{-1}$.

3. External hazard index ($H_{ex}$) and internal hazard index ($H_{in}$)

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} < 1 \quad \text{----------Eq.3}$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} < 1 \quad \text{----------- Eq.4}$$

Where $A_{Ra}$, $A_{Th}$ and $A_K$ represent the activity concentration (Bq/kg) of $^{226}$Ra, $^{232}$Th and $^{40}$K respectively.



4. Absorbed indoor dose rate ($D_{in}$) and outdoor dose rate ($D_{out}$)

$$D_{out} = 0.4551 \times A_{Ra} + 0.5835 \times A_{Th} + 0.0429 \times A_K \text{----------- Eq.5}$$

$$D_{in} = D_{out} \times 1.4 \text{ ------------- Eq.6}$$

5. Annual indoor effective dose ($E_{in}$)

$$(E_{in}) = D_{in}(nGy.h^{-1}) \times 8760(h) \times 0.7(SvGyh^{-1}) \times 0.8 \times 10^{-6} \text{ ----------- Eq.7}$$

In Table 2-6, limiting values of natural radiation are presented. These values are based on international publications as indicated in the Table 2-6.

Table 2-6: Limiting values of radiological hazard indicators from the literatures

| Indicator | | Limiting Value | Reference |
|---|---|---|---|
| Activity Concentration(Bq/kg) | $^{226}Ra$ | ***50 (Avg)*** | *NEA-OECD 1979* |
| | $^{232}Th$ | ***50 (Avg)*** | *-do-* |
| | $^{40}K$ | ***500 (Avg)*** | *-do-* |
| $Ra_{eq}$ (Bq/kg) | | ***<370*** | Beretka & Mathew 1985 |
| Criteria formula | Eq.2 | ***<1*** | Keller & Muth 1990 |
| Hazard Indices | $H_{ex}$ Eq.3 | ***<1*** | Beretka & Mathew 1985 |
| | $H_{in}$ Eq.4 | ***<1*** | *-do-* |
| Absorbed indoor dose rate Eq.5,Eq.6 ($nGyh^{-1}$) | | ***84 (Avg)*** | Quindos & Arteche 2004, UNSCEAR 2000 |
| Annual effective dose ($mSvy^{-1}$) Eq.7 | | ***0.45 (Avg)*** | UNSCEAR 1993 |

Comparison could be done for the Activity concentration of bottom ash, bottom ash block and river sand blocks tested in this research with the typical activity concentrations.



In Table 2-7 radiation activity concentration of common building materials are given based on national and international documents.

Table 2-7: Radiation activity concentration of common building materials

| Country | Building Material | Typical Activity Concentration (Bq/kg) | | | $Ra_{eq}$ (Bq/kg) | Reference |
|---|---|---|---|---|---|---|
| | | $^{226}Ra$ | $^{232}Th$ | $^{40}K$ | | |
| EU countries | Concrete | 40 | 30 | 400 | 113 | European commission 1999Directorate -General Environment, Nuclear Safety and Civil Protection |
| | Aerated & light-weight concrete | 60 | 40 | 430 | 150 | |
| | Clay(red) bricks | 50 | 50 | 670 | 173 | |
| | Sand-lime bricks | 10 | 10 | 330 | 50 | |
| | Natural building stone | 60 | 60 | 640 | 195 | |
| | Natural Gypsum | 10 | 10 | 80 | 30 | |
| | Blast furnace slag | 270 | 70 | 240 | 388 | |
| | Coal fly ash | 180 | 100 | 650 | 373 | |
| Sri Lanka | Clay brick | 35 | 72 | 585 | 183 | Hewamanna et al. 1999 |



As a general safety measure, health risks associated working with bottom ash can be minimized by wearing necessary safety wear such as respirator, safety goggle, Alkali-resistant gloves, boots and long-sleeved protective clothing. Arsenic content and radiation of bottom ash to be tested time to time to keep the workers not to exceed the limit of exposure to Arsenic and radiation effect, when bottom ash is put into use.

Annual effective dose

To estimate the annual effective dose, one has to take into account the conversion factor from the absorbed dose ($Gy.h^{-1}$) in air to the effective dose ($Sv\ h^{-1}$) and the indoor occupancy factor. In the recent reports, a value of $0.7Sv.y^{-1}$ was used for the conversion factor from the absorbed dose in air to the effective dose received by adults, and 0.8 for the indoor occupancy factor, implying that 80% of time is spent indoors, on average, around the world (UNSCEAR 2000).

Therefore, the annual effective doses ($mSv.y^{-1}$) for indoors received by adults were estimated using the following formula.

$$\text{Indoors } (E_{in}) = D_{in}(nGy.h^{-1}) \times 8760(h) \times 0.7(SvGyh^{-1}) \times 0.8 \times 10^{-6}$$

The population weighted Sri Lankan average is $0.20 mSvy^{-1}$. National estimates of average annual effective dose from terrestrial gamma rays for 13 countries is given in (UNSCEAR 1993) and has a population weighted world average of $0.45 mSvy^{-1}$. Table 2-8 indicates the activity concentration of most common building materials, which is useful to compare the traditional and most recent building materials.

Table 2-8: Typical and maximum activity concentrations in common building materials and industrial by-products used for building materials in the EU.

| Material | Typical activity concentration (Bq $kg^{-1}$) | | | Maximum activity concentration (Bq $kg^{-1}$) | | |
|---|---|---|---|---|---|---|
| Most common building materials (may include by-products) | $^{226}Ra$ | $^{232}Th$ | $^{40}K$ | $^{226}Ra$ | $^{232}Th$ | $^{40}K$ |
| Concrete | 40 | 30 | 400 | 240 | 190 | 1600 |
| Aerated and light-weight concrete | 60 | 40 | 430 | 2600 | 190 | 1600 |
| Clay (red) bricks | 50 | 50 | 670 | 200 | 200 | 2000 |
| Sand-lime bricks | 10 | 10 | 330 | 25 | 30 | 700 |
| Natural building stones | 60 | 60 | 640 | 500 | 310 | 4000 |
| Natural gypsum | 10 | 10 | 80 | 70 | 100 | 200 |
| By-product gypsum (Phosphogypsum) | 390 | 20 | 60 | 1100 | 160 | 300 |
| Blast furnace slag | 270 | 70 | 240 | 2100 | 340 | 1000 |
| Coal fly ash | 180 | 100 | 650 | 1100 | 300 | 1500 |



Source: *Radiological Protection Principles concerning the Natural Radioactivity of Building Materials European Commission 1999* (Radiation Protection 112)

Typical concentrations are population-weighted national means of different Member States. Maximum concentrations are maximum values reported in references. Higher values might have been reported elsewhere.

## 2.6 Thermal Properties of Bottom Ash Blocks

The comfort of a dweller within a building is affected by the heat transmitted across the bricks or blocks in the wall of the building. Hence thermal properties of blocks are important in evaluating their performance as masonry units.
Thermal properties are not specified as essential requirements in the Sri Lanka standards for bricks or blocks (SLS 855-1: 1989).

Thermal conductivity is the property of a material to conduct heat. Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. Given two surfaces on either side of the material with a temperature difference between them, the thermal conductivity is the heat energy transferred per unit time and per unit surface area, divided by the temperature difference.

Specific heat capacity and thermal diffusivity are also measures of thermal properties. A low value of thermal conductivity is desired for the bricks as this means that heat conduction within the brick is minimized, qualifying the brick to be a good insulator. Thermal conductivity of bricks made from coal ash and fly ash is lower than that of clay bricks (Sandra 2009).

# CHAPTER 3

## 3. RESEARCH METHODOLOGY

### 3.1 Sampling of Bottom Ash

The practice adapted at the power plant is to dump the bottom ash produced in one day at a given point. The next day it is taken away from that point and spread over a large area using a back-hoe. Fig. 3-1 shows that bottom ash dumped in the ash pond of power plant. Fig. 3-2 & 3-3 show sampling of bottom ash from bottom ash piles after removing top layer of at least 150 mm and to represent the batch by taking from equal interval, then loading to the vehicle. Sampling was done as per British Standard (BS EN 932-1:1997).



Figure 3-1 : Large area of land covered with bottom ash in the ash pond of power plant

Figure 3-2 : Sampling of bottom ash



Figure 3-3 : Bottom ash sample is loaded to the vehicle

This research was carried out during the period from 2012 to 2014. During this period bottom ash samples were collected four times with equal time interval. Sampling details are presented in Table 3-1. Source of coal during this period was from Indonesia.

Table 3-1: Details of sampling

| Sample No | Date of sampling | Quantity | Properties tested |
|---|---|---|---|
| 1 | Not known* | 100kg | chemical and physical |
| 2 | 14.03.2013 | 250kg | chemical, physical, thermal and Cinva-Ram trials |
| 3 | 05.08.2013 | 350kg | chemical, physical, thermal, radiation and conventional cement block trials |
| 4 | 05.12.2013 | 750kg | chemical, physical, thermal and conventional cement block trials |

*During 2012 by Environmental Division of NBRO

Since bottom ash is produced continuously and the source of coal was the same during the research period, the quantity produced within a three to four-month period was treated as a batch. A bulk sample was taken to represent average properties of a batch.

A specified apparatus as per the standard was used to take a sample in order to avoid biased sampling. Adequate number of sampling increments was taken to avoid sampling variation caused by the heterogeneity of the batch. Sampling increments were selected at random from all the parts of a batch that the batch sample is to represent.



The following equation was used to decide the minimum mass of a bulk sample as per BS EN 932-1:1997.

$M = 6 \times \sqrt{D} \times \ell_b$

M- Mass of the sample in kg

D- Maximum grain size in mm

$\ell_b$ – Loose bulk density in Mega-grams per cubic metre

## 3.2 Determination of Properties of Bottom Ash

Chemical composition, loss on ignition, leaching properties, radiation effect, sieve analysis, particle density and water absorption, loose bulk density, microstructure and strength of mortar were tested for bottom ash. Test methods given in British standard and American Standards were used for these tests. Tests results were compared with test results on river sand derived from previous studies (Savitha & Ranatunge 2010).

Bottom ash sampled as Table 3-1 were tested for the following physical and chemical properties: gradation, fines content, fineness, particle density and water absorption, bulk density, microstructure, loss on ignition, mineralogical analysis and chemical analysis for the content of Mg, Pb, Cr, Cd, Cu, Ni, and Se and effects of leaching of these elements and radiation effects.

### 3.2.1 Chemical properties

Chemical analysis is important to find out the composition and harmful elements in bottom ash. It was carried out using Atomic Absorption Spectroscopy.



### 3.2.2 Loss on ignition

Usually Loss on Ignition (LOI) test is carried out for cement and not for aggregate. However, this test should be carried out for bottom ash in order to detect the presence of partially burnt coal in bottom ash sample. Bottom ash containing partially burnt coal cannot be used for block making as it can adversely affect the mechanical and physical properties of the block. Testing was carried out as per Sri Lanka Standard (SLS 107-2 : 2008).

### 3.2.3 Leaching properties

This test determines the possibility of leaching harmful metals from the bottom ash block. Leachability test was done by agitating the sample in water and keeping for 24 hours followed by testing the water for harmful elements. Testing was carried out as per American Standard (ASTM D 3987 : 2006).

### 3.2.4 Radiation effect

If radioactive materials are present in bottom ash, people handling and using the product made out of bottom ash will face health problems. Therefore, presence of such materials in bottom ash was checked by testing a sample at the Atomic Energy Authority Laboratory. Test was carried out by using High Purity Germanium Detector (HPGD).

### 3.2.5 Sieve analysis

Particle size distribution of bottom ash is important for proper packing. Testing was carried out as per British Standard (BS EN 933-1: 1997).

### 3.2.6 Particle density & water absorption

Particle density and water absorption are important to predict the behavior of block produced with bottom ash. Tests were carried out as per British Standard (BS EN 1097-6 : 2000).

### 3.2.7 Loose bulk density



Usually, mix by volume is used in cement block manufacturing. Therefore, loose bulk density was determined as per British Standard (BS EN 1097-3 : 1998).

### 3.2.8 Microstructure of bottom ash

Shape and microstructure of bottom ash particles were observed using scanning electron microscope.

### 3.2.9 Effect of particle size fraction on strength of cement mortars

Mortar cubes made with bottom ash were tested in accordance with American Standard (ASTM C 87 : 2010) in order to check the influence of particle size fraction of bottom ash on strength properties. Two size fractions of bottom ash (i.e. particles < 4 mm and 600-800µm) were tested and compared with same size fractions of river sand.

### 3.3 Survey on Block Production

In order to assess the present situation of cement block making in Sri Lanka, about ten block manufacturers in the western province (mainly, Nawala, Homagama and Moratuwa area) were interviewed. The outcome of interviews including their production details and experience were used to study common compositions to select suitable mixes.

In Sri Lanka, cement block making is carried out using a conventional type of machine in which the cement-aggregate mixture is vibrated first and the pressure is applied for better bonding. Usually local small scale cement block manufacturers use 1:20 (cement: aggregate) mix by volume.

However, manufacturers who are more concerned about quality would limit this mix to 1:9 with control on moisture content of aggregate, thus making it possible to comply with the requirements on water absorption, density and compressive strength tests as per Sri Lanka standard (SLS 855 : Part 1: 1989).



### 3.4 Determination of Properties of Bottom Ash Blocks Produced with Cinva-Ram Machine

The main objective of this research was to investigate the possibility of utilizing the bottom ash from coal fired power plants to produce light weight building blocks for building construction. The other objective was to produce a cost effective cement block suitable for small or medium scale production using locally available machinery and raw materials.

Bottom ash collected from Nuraicholai power plant was processed by sieving or grinding and sieving if needed to obtain particle size less than 4 mm. Mortar/concrete mixes were designed with bottom ash for carrying out trials on the production of blocks with Cinva-Ram machine and with conventional cement block making machine. Fresh properties of mortar/concrete were determined. Mechanical and thermal properties of blocks produced as trials with selected mixes were tested.

From the questionnaire survey of cement block manufacturers, it was found that up to 1:20 cement: aggregate by volume with or without admixture is used to produce cement blocks. As the first trial cement mortar blocks with bottom ash were produced with Cinva-Ram machine where only pressure is applied for compaction. Figure 3-4 & 3-5 show Cinva-Ram machine filled with mortar mix and pressure is being applied.

Figure 3-4 : Cinva-Ram machine



Figure 3-5 : Cinva- Ram machine moulds filled with mortar mix and machine is in operation

Materials used for bottom ash block produced with Cinva- Ram machine were:

1. Cement: OPC 42.5N
2. Sieved Bottom Ash (<4 mm)

The mix proportions of cement and bottom ash were selected based on mix proportions used by cement block manufacturers in the Western Province, Sri Lanka.

The selected volume proportions of cement: bottom ash were 1:3, 1:6, 1:8, 1:13, 1:22 and 1:26.

## 3.5 Determination of Properties of Bottom Ash Blocks Produced with Cement Block Making Machine

In the second stage of producing cement blocks, conventional block making machine was used. Materials used for bottom ash block produced with Conventional Cement Block Making Machine were:

1. Cement: OPC 42.5N
2. Sieved Bottom Ash (<4 mm)
3. Sieved River Sand (<4 mm)
4. Crushed Rock Sand (<4 mm)
5. Gravel (5-10 mm graded)

Physical properties of bottom ash blocks produced using the Conventional Cement Block Making Machine were determined using Sri Lanka Standard test methods (SLS 855-2: 1989).



### 3.5.1 Thermal properties of bottom ash blocks

When blocks are produced with bottom ash, better insulation is expected. In order to verify this fact, thermal properties of bottom ash blocks should be tested. To find out the thermal behavior of bottom ash blocks, thermal conductivity which is a measure of how readily a material can conduct heat, specific heat which is ability of a substance to store thermal energy and thermal diffusivity which is ratio of thermal conductivity to heat capacity were determined. Hot-wire method (Sandra 2009) was used to determine the thermal conductivity and thermal diffusivity (Figure 3-6 to 3-9).

Hot-Wire Method

In this method, hot wire (Ni-Cr wire) was mounted centrally and thermocouples were spaced in equal measured distances. Temperature with time were recorded with a data logger and calculations were carried based on the methods described in reference (Prabhath et al., 2014) Figures 3-6 to 3-10 shows the steps in the hot wire test procedure.

Figure 3-6 : Thermocouples are arranged at required depth and distances



Figure 3-7 : Casting of bottom ash mortar specimen

Figure 3-8 : Hot wire testing arrangement

### 3.5.2 Drying shrinkage and wetting expansion

For drying shrinkage and wetting expansion test, in order to represent cement rich mix and bottom ash rich mix, standard mixes 1:3 and 1:6 were selected to carry out drying shrinkage and wetting expansion tests. Figures 3-10 to 3-12 show test equipment and method of the tests. Tests were carried out as per the test method stated in SLS 855-2: 1989.

Figure 3-9 : Humidity Cabinet to maintain 17% humidity at 50°C



Figure 3-10 : Samples arranged in a humidity cabinet

Figure 3-11: Length comparator to measure change in length

## CHAPTER 4

# 4. ANALYSIS OF TEST RESULTS

### 4.1 Evaluation of Bottom Ash Properties

#### 4.1.1 Chemical properties

Chemical analysis was carried out using Atomic Absorption Spectroscopy on Nuraicholai power plant bottom ash waste and given in Table 4-1. The limiting values of the harmful elements specified in EPA (Environmental Protection Agency) are also given in Table 4-1. It can be seen that the concentrations of harmful elements present such as As, Pb, Cr, Cd, Cu, Ni and Se were below the internationally specified toxicity limits for use in soil as a filling material as per U.S. Environmental Protection Agency.

Table 4-1: Composition of bottom ash



| Parameter | Unit | Observed Value | | Limiting value specified in EPA, US in uncontaminated soil used as fill material at regulated fill operations |
|---|---|---|---|---|
| | | Minimum | Maximum | Value |
| As | mg/kg | 0.62 | 4.9 | <11.3 |
| Mg | mg/kg | 37.0 | 220.0 | < 325,000 |
| K | mg/kg | <20.0 | 211.0 | - |
| Na | mg/kg | 80.0 | 782.0 | - |
| Ca | g/kg | 0.66 | 5.20 | - |
| Al | g/kg | 1.8* | 1.8* | - |
| Fe | g/kg | 4.37g/kg | 33.85 | - |
| $SiO_2$ | % | 88 | 98 | - |
| Pb | mg/kg | <LDL(2ppm) | | < 107 |
| Cr | mg/kg | <LDL(2ppm) | | < 21 |
| Cd | mg/kg | <LDL(0.2ppm) | | < 5.2 |
| Cu | mg/kg | <LDL(1.0ppm) | | < 2900 |
| Ni | mg/kg | <LDL( 2ppm)- | 2 | < 100 |
| Se | mg/kg | <LDL ( 20ppb) | | < 1.3 |

LDL-Lower Detection Limit

*only one sample checked for this mineral

As per international requirements, concentrations of all the tested heavy metals are within the allowable limit for soil. Among the toxic heavy metals present in bottom ash, Arsenic (As) is having the highest percentage.

Arsenic is a semi-metal element in the Periodic Table. It is odorless and tasteless. Effects of As are thickening and discoloration of the skin, stomach pain, nausea, vomiting, diarrhea, paralysis, blindness and cancer. Even though the amount of As in bottom ash is within the specified limits for soil, continuous exposure to bottom ash may be harmful. Therefore, safety shoes, clothes & gloves should be used when work with bottom ash.

### 4.1.2 Loss on Ignition of bottom ash

Values observed for bottom ash were in the range of 1-2%. Observed value indicates that negligible unburnt coal and moisture of the tested samples.

### 4.1.3 Leaching properties



Test results of bottom ash obtained by Environmental Division of National Building Research Organization and Chemical Department of University of Colombo showed that there was no As, Pb and Se metals leached to water. As per the sample tested, there was no possibility of leaching harmful metals from the bottom ash.

### 4.1.4 Radiation effect

Sample of bottom ash from the Nuraicholai power plant was tested for the levels of radioactive emission by Atomic Energy Authority using Gamma Spectrometry with high purity Germanium detector. From the reported results given in Table 4-2, radium equivalent values were calculated using the equation 1 in Chapter 2. Results given in Table 4-2 were comparable with the emission levels found in other common building materials such as soil or sand. According to the test report by AEA, bottom ash was neutral and it can be used for building material making without any fear of radiation effect.

Table 4-2: Results of analysis of radioactivity

| Sample | Radio Nuclide | Activity (Bq/kg) |
| --- | --- | --- |
| bottom ash | K-40 | 98±7 |
| | Pb-210 | NOT DETECTED (minimum detectable activity is 8.0) |
| | Ra-226 | 29±2 |
| | Th-232 | 37±3 |
| block produced from bottom ash as a fine aggregate | K-40 | 92±6 |
| | Pb-210 | 16±3 |
| | Ra-226 | 28±2 |
| | Th-232 | 37±3 |
| block produced from river sand as a fine aggregate | K-40 | 159±9 |
| | Pb-210 | 8±1 |
| | Ra-226 | 13±1 |
| | Th-232 | 33±2 |

Table 4-3: Radiation properties of bottom ash and blocks

| Sample | Radium Equivalent Value (Bq/kg) |
| --- | --- |
| bottom ash | 89 |
| block produced from bottom ash as a fine aggregate | 87 |
| block produced from river sand as a fine aggregate | 71 |



OECD Radium equivalent value limit for building material is 370Bq/kg. Therefore, this bottom ash sample is safe with respect to harmful radiation effect in respect of radium equivalent value.

### 4.1.5 Sieve analysis

Test results of particle size distribution of bottom ash samples showed that samples 1 & 2 do not comply with the grading limits specified in BS EN 12620:2002. Sample No 3&4 complied with grading limits specified in BS EN limits for medium graded fine aggregate. Table 4-4 shows the summary of gradation and fines content (< 63μm) in the samples tested. Tables 4-5 to 4-9 present detail of sieve analysis and Figures 4-1 to 4-5 give relevant graphs. Detail test results are given in the Annexure1.

Table 4-4: Summary of gradation and fines content in bottom ash samples

| Sample No. | Gradation | Fines content % |
|---|---|---|
| 1 | 0 -16 mm | 8.5 |
| 2 | 0 -16 mm | 1.7 |
| 3 | 0 – 4 mm | 23.1 |
| 4 | 0 – 4 mm | 16.3 |

Table 4-5: Sieve analysis of bottom ash Sample 1

| Sieve Size (mm) | Percentage mass passing | Specified limits for coarse zone fine aggregate D≤4 mm and d=0 (BS EN 12620: 2002) |
|---|---|---|
| 16.0 | 100.0 | 100 |
| 8.0 | 81.8 | 100 |
| 5.0 | 72.6 | 95-100 |
| 4.0 | 68.4 | 85-99 |
| 0.500 | 34.3 | 5-45 |
| 0.063 | 8.5 | 0-3 |
| Pan | 0 | |

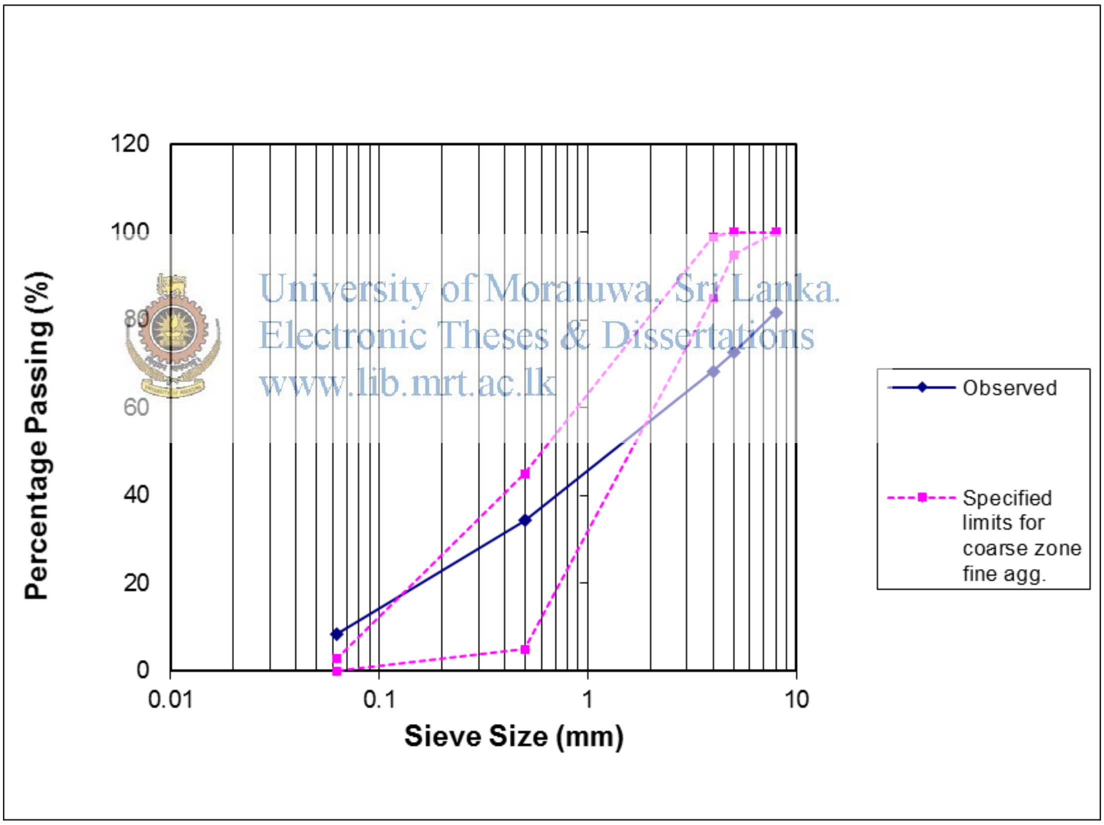




Figure 4-1: Grading Curve of Bottom Ash Sample 1

Table 4-6: Sieve analysis of bottom ash Sample 1 after removing over 8mm particles

| Sieve Size (mm) | Percentage mass passing | Specified limits for coarse zone fine aggregate D≤4 mm and d=0 (BS EN 12620: 2002) |
|---|---|---|
| 8.0 | 100.0 | 100 |
| 5.0 | 89.6 | 95-100 |
| 4.0 | 84.3 | 85-99 |
| 0.500 | 42.2 | 5-45 |
| 0.063 | 10.5 | 0-3 |
| Pan | 0 | |

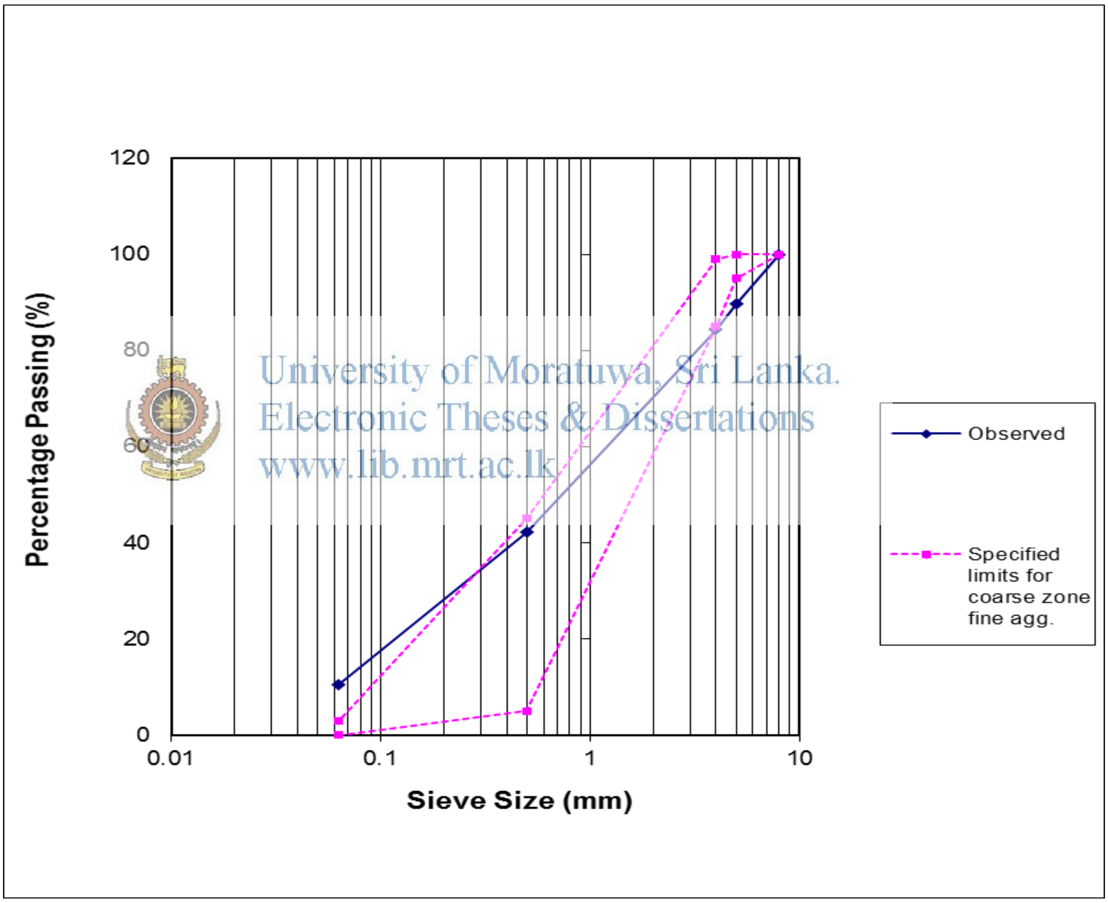




Figure 4-2: Grading Curve of Bottom Ash Sample 1(<8mm)

Table 4-7: Sieve analysis of bottom ash Sample 2

| Sieve Size (mm) | Percentage mass passing | Specified limits for medium zone fine aggregate D≤4 mm and d=0 (BS EN 12620: 2002) |
|---|---|---|
| 8.0 | 97.3 | 100 |
| 5.0 | 94.0 | 95-100 |
| 4.0 | 91.3 | 85-99 |
| 0.500 | 67.1 | 55-100 |
| 0.063 | 1.7 | 0-3 |
| Pan | 0 | |

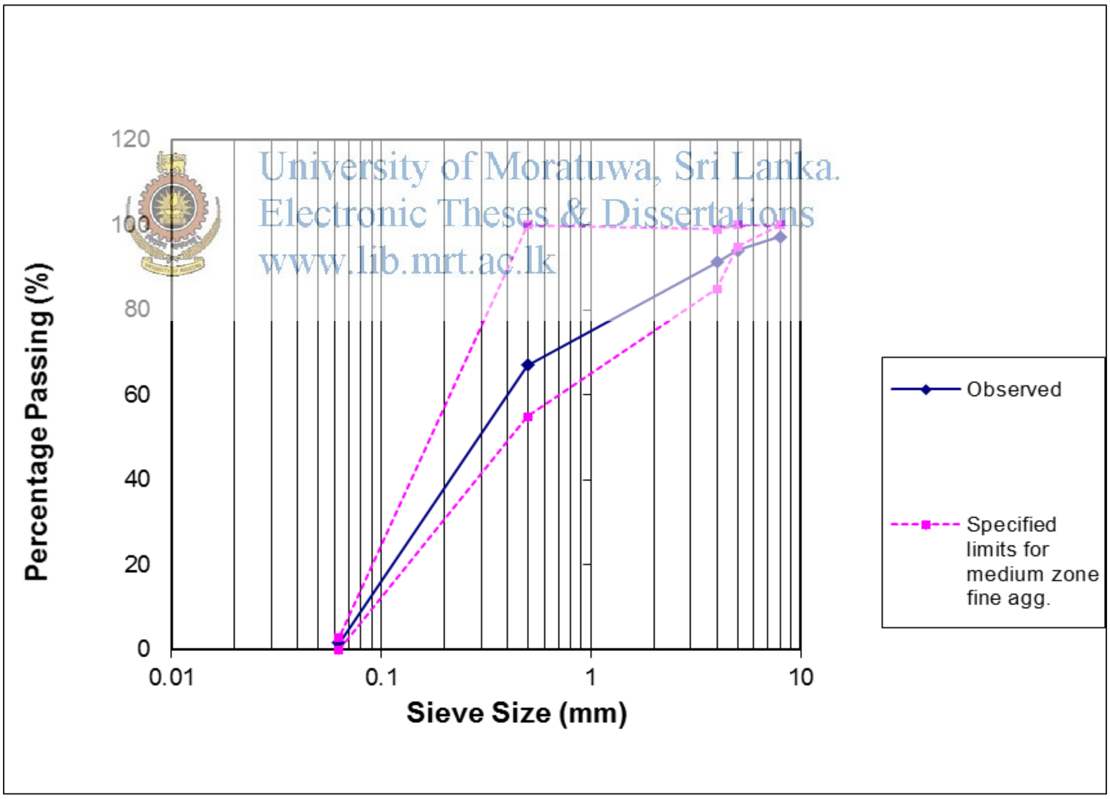



Figure 4-3: Grading Curve for Bottom Ash Sample 2

Table 4-8: Sieve analysis of bottom ash Sample 3

| Sieve Size (mm) | Percentage mass passing | Specified limits for medium zone fine aggregate D≤4 mm and d=0 (BS EN 12620: 2002) |
|---|---|---|
| 8.0 | 100.0 | 100 |
| 5.0 | 99.0 | 95-100 |
| 4.0 | 98.4 | 85-99 |
| 0.500 | 82.9 | 55-100 |
| 0.063 | 23.1 | 0-3 |
| Pan | 0 | |

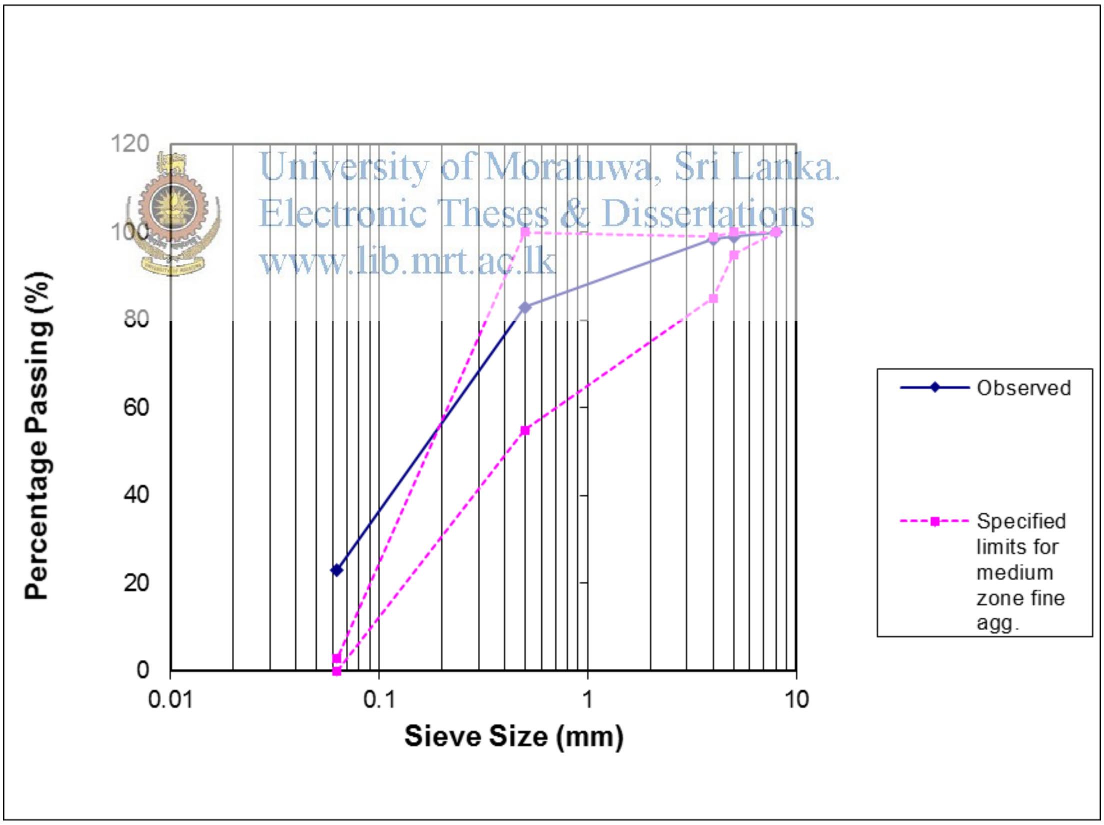




Figure 4-4: Grading Curve for Bottom Ash Sample 3

Table 4-9: Sieve analysis of bottom ash Sample 4

| Sieve Size (mm) | Percentage mass passing | Specified limits for medium zone fine aggregate D≤4 mm and d=0 (BS EN 12620: 2002) |
|---|---|---|
| 8.0 | 95.7 | 100 |
| 5.0 | 94.0 | 95-100 |
| 4.0 | 89.1 | 85-99 |
| 0.500 | 66.2 | 55-100 |
| 0.063 | 16.3 | 0-3 |
| Pan | 0 | |

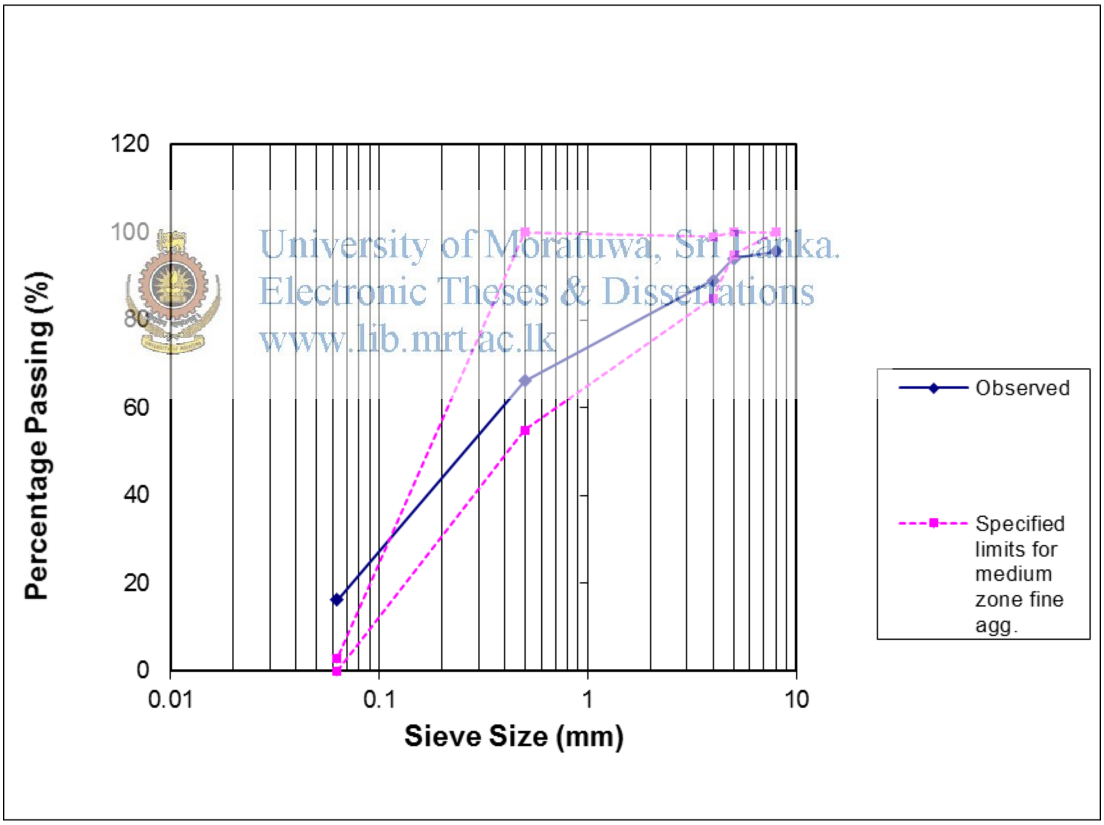



Figure 4-5: Grading Curve for Bottom Ash Sample 4

### 4.1.6 Particle density & water absorption

Test results of particle density and water absorption of the bottom ash samples are given in Table 4-10. Detail results are given in annexure 1. It can be seen that particle density of bottom ash is in the range of 1500-1750kg/m$^3$ and water absorption is in the range of 17-30% by dry mass while river sand had particle density of 2600-2750 kg/m$^3$ and water absorption of 0.4-1.0% (Savitha & Ranatunge 2010). Low particle density will be an advantage in producing a light weight block, however higher water absorption by bottom ash can cause a problem.

Table 4-10: Particle densities & Water absorption of bottom ash samples

| Sample No | Particle Density (kg/m$^3$) | | Water Absorption (%) |
|---|---|---|---|
| | Saturated Surface dry condition | Oven dry condition | |
| 1 | 1750 | 1490 | 17.4 |
| 2 | 1740 | 1470 | 18.4 |
| 3 | 1550 | 1200 | 29.1 |
| 4 | 1670 | 1280 | 30.5 |



### 4.1.7 Loose bulk density

Test results of loose bulk density of the bottom ash samples are given in Table 4-11. Detail results are given in the Annexure 1. Bottom ash had loose bulk density of 590-770 kg/m$^3$, while loose bulk density of river sand and crushed rock sand were 1450 and 1500 kg/m$^3$ respectively (Savitha & Ranatunge 2010).

Table 4-11: Loose bulk density of bottom ash

| Sample No. | Loose Bulk Density at oven dry condition (kg/m$^3$) |
|---|---|
| 1 | 590 |
| 2 | 650 |
| 3 | 750 |
| 4 | 770 |

### 4.1.8 Microstructure of bottom ash

When a sample of bottom ash was examined using a scanning electron microscope, irregular particles with large amount of pores were observed (Fig 4-6 & 4-7), thus giving the low particle density.

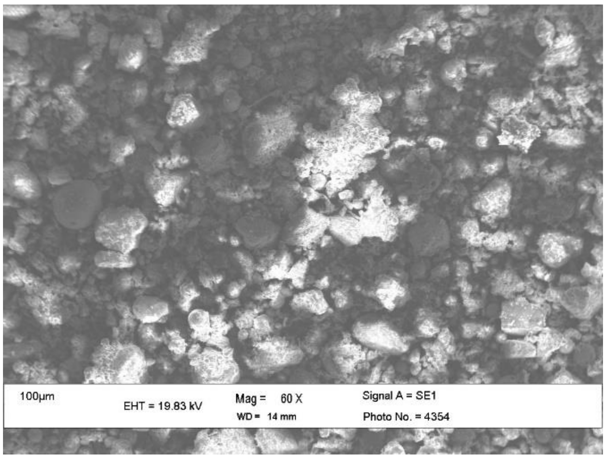


Figure 4-6: SEM image of as received bottom ash at mag.60



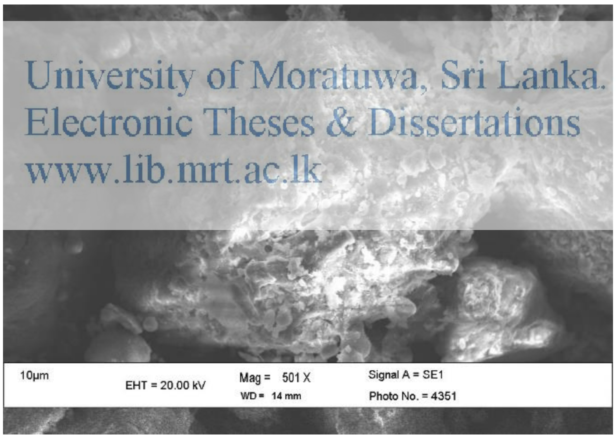


Figure 4-7: SEM image of as received bottom ash at mag.500

### 4.1.9 Mortar cube testing

A standard mortar mix of cement and bottom ash in the ratio of 1:3 by volume was prepared as per the method specified in BS 12: 1996 (Specification for Portland cement) and 70mm x 70mm x 70mm mortar cubes were prepared for testing. Compaction was applied using vibrating table. The tests were repeated by replacing bottom ash with river sand in order to compare the performance of the two materials. The test results obtained are given in Table 4-12.

Table 4-12: Test results of mortar cubes

| Type of aggregate | Mix | | W/C Ratio By weight | Saturated Density ($kg/m^3$) | Compressive Strength ($N/mm^2$) | |
|---|---|---|---|---|---|---|
| | By Volume | By Weight | | | 3-day | 28-day |
| Bottom Ash (<4mm) | 1:3 | 1:1.5 | 0.45 | 1850 | 12.7 | 28.8 |
| River Sand(<4mm) | 1:3 | 1:3.15 | 0.45 | 2450 | 28.8 | 59.4 |

Cement mortar with bottom ash had nearly half the strength of cement mortar with river sand. In order to find out the reason for the difference in strength, a narrow range of particles was used in testing. Both fine aggregates were reduced to smaller particle size fractions and 600-800µm particles were used for testing. Results are given in Table 4-13. If water cement ratio is kept as constant for trials with bottom ash and river sand it was not possible to cast cubes, because mortar mix was not workable. Therefore, two different water cement ratios were used in the trials. Water/Cement ratios reported (aggregates were S.S.D level) in Table 4-13 gave same plunger penetration value (same consistency). Therefore, it was not possible to make a conclusion on whether difference in strength is due to large amount of pores in bottom ash or Water/Cement ratio.



Table 4-13: Test results of mortar cubes with narrow/small particle range/size

| Type of aggregate | Mix | | W/C Ratio By weight | Saturated Density ($kg/m^3$) | Compressive Strength ($N/mm^2$) | |
|---|---|---|---|---|---|---|
| | By Volume | By Weight | | | 3-day | 28-day |
| Bottom ash (600-800µm) Loose Bulk Density-850kg/$m^3$ | 1:3 | 1:2.36 | 0.40 | 1800 | 6.5 | 8.8 |
| River Sand (600-800µm)Loose Bulk Density-1410 kg/$m^3$ | 1:3 | 1:4.45 | 0.26 | 2240 | 6.8 | 12.4 |

## 4.2 Blocks Produced with Cinva-Ram Machine and Their Properties

Figure 4-8 shows blocks produced with Cinva-Ram machine. Test results of Cinva-Ram block trials are presented in Table 4-14.

Figure 4-8: Cement-Bottom ash block produced with Cinva-Ram machine

Table 4-14 :Test results of properties of bottom ash blocks

| Mix by volume | w/c ratio by volume | Density As received ($kg/m^3$) | Water Absorption ($kg/m^3$) | Moisture content (%) | Compressive strength ($N/mm^2$) | Depth of penetration (Erosion test as per SLS) (mm) |
|---|---|---|---|---|---|---|
| 1:3 | 0.21 | 1150 | 265 | 5.9 | 11.3 | 0 |
| 1:6 | 0.37 | 1100 | 284 | 4.2 | 3.3 | 0 |
| 1:8 | 0.56 | 960 | 444 | 3.7 | 2.2 | 0 |
| 1:13 | 0.76 | 930 | 488 | 5.7 | 1.4 | 4 |
| 1:22 | 1.17 | 730 | 517 | 6.2 | 0.4 | >10 |
| 1:26 | 1.35 | 760 | 555 | 7.0 | 0.3 | >10 |



Water to cement ratio for each mix was decided by doing drop test. In each mix proportions, at least four samples were tested. Initially, a suitable mix proportion (by weight) was selected based on commonly used mix proportions in Sri Lanka for ordinary cement block manufacturing. Then it was converted to volume basis.

The SLS 855: 1989 specified that the strength of blocks (produced with whatever mix) should be equal or exceed 1.2 N/mm$^2$ and that the water absorption should not exceed 240 kg/m$^3$.

According to the test results given in Table 4-14, none of the mixes satisfies the water absorption requirement. Therefore, when selecting mix proportions for the second stage of producing blocks, quarry dust and coarse aggregate (5-10mm) were considered to reduce the water absorption. Compressive strength test carried out for river sand block with 1:3 by volume proportion also gave the compressive strength of 10.1 N/mm$^2$. However, it was not possible to keep constant water cement ratio due to consistency requirement. Mix proportion 1:6 or more with river sand could not be produced with this machine, because green strength was insufficient.

## 4.3 Properties of Blocks Produced with Cement Block Making Machine

### 4.3.1 Compressive strength and water absorption

Figure 4-9 shows cement-bottom ash blocks produced with cement block making machine.




Figure 4-9: Cement- Bottom ash blocks produced with cement block making machine

Test results of mixes with and without bottom ash with conventional cement block making machine are presented in Tables 4-15. For each mix proportions, four blocks were tested and individual results of each blocks are given in the Annexure 2. Reported results in Table 4-15 were the arithmetic mean of four or more individual results. Details of individual test results and comparison using student T-analysis are given in Annexure 2. Blocks with several mix proportions as given in Table 4-15 were tested in order to find out the proper mix which will give all the required properties as per SLS 855. The mix proportions satisfying and unsatisfying the SLS 855 requirements are given in in Table 4-16 and 4-17 respectively.

Table 4-15 : Results of blocks made with conventional cement block making machine

| Mix No. | Mix proportion by volume | | | | | | Properties | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cement | River sand | Quarry dust | Bottom ash | Crushed rock agg. (5-10mm) | Water | Density ($kg/m^3$) | Water absorption ($kg/m^3$) | Compressive strength at 28 days ($N/mm^2$) |
| RQ 1 | 1 | 3 | 3 | 0 | 0 | 0.9 | 1913 | 203 | 5.6 |
| QB 1 | 1 | 0 | 3 | 3 | 0 | 1.17 | 1501 | 290 | 4.1 |
| RQC 1 | 1 | 2 | 2 | 0 | 3 | 1.0 | 2214 | 88 | 8.8 |
| QBC 1 | 1 | 0 | 2 | 2 | 3 | 1.2 | 1958 | 143 | 6.4 |
| BC 1 | 1 | 0 | 0 | 4 | 3 | 1.8 | 1701 | 167 | 4.6 |
| QC 1 | 1 | 0 | 4 | 0 | 3 | 1.0 | - | - | 9.1 |
| QB 2 | 1 | 0 | 3 | 4 | 0 | 2.8 | 1636 | - | 3.9 |
| QBC 2 | 1 | 0 | 1 | 3 | 1.5 | 1.5 | 1807 | 152 | 5.2 |
| B 1 | 1 | 0 | 0 | 7 | 0 | 3.0 | 1127 | 350 | 1.2 |
| QBC 3 | 1 | 0 | 2 | 3.5 | 1 | 2.0 | 1777 | 116 | 4.2 |
| QC 2 | 1 | 0 | 12 | 0 | 8 | 2.8 | 2051 | 179 | 1.2 |
| BC 2 | 1 | 0 | 0 | 12 | 8 | 5.0 | 2049 | 181 | 1.5 |
| RQ 2 | 1 | 4 | 5 | 0 | 0 | 1.0 | 1953 | 186 | 4.2 |
| QB 3 | 1 | 0 | 5 | 4 | 0 | 1.9 | 1501 | 306 | 3.5 |
| BC 3 | 1 | 0 | 0 | 7 | 3 | 1.2 | 1499 | 298 | 2.3 |
| BC 4 | 1 | 0 | 0 | 14 | 6 | 4.0 | 1385 | 327 | 1.0 |
| BC 5 | 1 | 0 | 0 | 9 | 4 | 1.7 | - | - | 1.6 |
| QBC 4 | 1 | 0 | 2 | 6 | 2 | 2.0 | 1442 | 298 | 2.0 |
| QBC 5 | 1 | 0 | 4 | 12 | 4 | 4.0 | 1435 | 298 | 0.8 |
| BC 6 | 1 | 0 | 0 | 6 | 4 | 2.0 | 1680 | 179 | 2.7 |

Table 4-16 shows the test results of mixes with cement, quarry dust, bottom ash and crushed rock aggregate combinations.

Table 4-16 : Results of blocks made with conventional cement block making machine satisfying SLS 855 requirements

| Mix No. | Mix proportion by volume | | | | | | Properties | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cement | River sand | Quarry dust | Bottom ash | Crushed rock agg. (5-10 mm) graded) | Water | Density ($kg/m^3$) | Water absorption ($kg/m^3$) | Compressive strength at 28 days ($N/mm^2$) |
| QBC 1 | 1 | 0 | 2 | 2 | 3 | 1.2 | 1958 | 143 | 6.4 |
| BC 1 | 1 | 0 | 0 | 4 | 3 | 1.8 | 1701 | 167 | 4.6 |
| QBC 2 | 1 | 0 | 1 | 3 | 1.5 | 1.5 | 1807 | 152 | 5.2 |
| QBC 3 | 1 | 0 | 2 | 3.5 | 1 | 2.0 | 1777 | 116 | 4.2 |
| BC 6 | 1 | 0 | 0 | 6 | 4 | 2.0 | 1680 | 179 | 2.7 |

It can be seen that the mix with bottom ash only (1:7) gives very high water absorption. It can also be seen that, only by replacing part of bottom ash with quarry dust, it was not possible to reduce the water absorption to an acceptable level. Therefore, coarse aggregate (5-10mm) was considered in the mix proportions. Mix proportions which gave satisfactory strength and water absorption are shown in Table 4-16, and all these mix proportions contain crushed rock aggregate (5-10mm). The mix proportions which were not satisfactory with respect to strength and water absorption are given in Table 4-17. Table 4-18 gives mix proportions satisfying the strength and water absorption requirements specified in SLS 855-1:1989.



Water content was altered to get the required consistency of the mix. If the water content is insufficient, then the compaction was difficult and if greater than the required value, then the water leaked out from the mould.

Bottom ash used in the trials were with following conditions,

a) Saturated Surface Dry condition

b) Sieved with 4 mm sieve

c) Without any unburnt coal

Table 4-17: Bottom ash mixes with unsatisfactory strength and water absorption

| Mix No. | Mix proportion by volume | | | | | | Properties | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cement | River sand | Quarry dust | Bottom ash | Crushed rock aggregate (5-10mm graded) | Water | Density (kg/m$^3$) | Water absorption (kg/m$^3$) | Compressive strength at 28 days (N/mm$^2$) |
| QB 1 | 1 | 0 | 3 | 3 | 0 | 1.17 | 1501 | 290 | 4.1 |
| QB 2 | 1 | 0 | 3 | 4 | 0 | 2.8 | 1636 | - | 3.9 |
| B 1 | 1 | 0 | 0 | 7 | 0 | 3.0 | 1127 | 350 | 1.2 |
| BC 2 | 1 | 0 | 0 | 12 | 8 | 5.0 | 2049 | 181 | 1.5 |
| QB 2 | 1 | 0 | 5 | 4 | 0 | 1.9 | 1501 | 306 | 3.5 |
| BC 3 | 1 | 0 | 0 | 7 | 3 | 1.2 | 1499 | 298 | 2.3 |
| BC 4 | 1 | 0 | 0 | 14 | 6 | 4.0 | 1385 | 327 | 1.0 |
| BC 5 | 1 | 0 | 0 | 9 | 4 | 1.7 | - | - | 1.6 |
| QBC 4 | 1 | 0 | 2 | 6 | 2 | 2.0 | 1442 | 298 | 2.0 |
| QBC 5 | 1 | 0 | 4 | 12 | 4 | 4.0 | 1435 | 298 | 0.8 |



Table 4-18: Mix proportions satisfying the strength and water absorption requirements specified in SLS 855-1:1989

| Property | Specified Value | Mix |
|---|---|---|
| Compressive strength | ≥1.2 N/mm$^2$ | RQ 1, QB 1, RQC 1, QBC 1, BC 1, QC 1, QB 2, QBC 2, B 1, QBC 3, QC 2, BC 2, RQ 2, QB 3, BC 3, BC 5, QBC 4, BC 6 |
| Water absorption | ≤240 kg/m$^3$ | RQ 1, RQC 1, QBC 1, BC 1, QBC 2, QBC 3, QC 2, BC 2, RQ 2, BC 6 |

Even though the minimum strength specified in SLS 855 is 1.2 N/mm$^2$, the minimum strength specified in BS 6073-1:1981 is 2.8 N/mm$^2$. When BS strength limit is considered, only the mixes given in Table 4-16 satisfy the required strength and water absorption. Mix BC 6 is marginally satisfying the strength requirement.

According to BS EN 206-1, the density limit for light weight concrete should be in the range of 800-2000 kg/m$^3$. All the mixes given in Table 4-16 satisfy this density limit for light weight concrete. The mix BC 6 gave the lowest density with satisfactory strength and water absorption.

### 4.3.2 Thermal cconductivity of bottom ash blocks

The thermal conductivity of bottom ash blocks made with the mix proportion 1:5 cement : bottom ash by volume was measured using hot-wire method and result is presented in Table 4-19.

Table 4-19: Measured thermal conductivity of bottom ash blocks

| Mix by volume (cement: bottom ash) | Thermal conductivity W/m.K |
|---|---|
| 1:5 | 0.54 |

Thermal conductivity of locally available good quality clay bricks and common cement blocks were tested using hot-wire method and results are presented in Table 4-20.

Table 4-20: Measured thermal conductivity of clay bricks and cement blocks

| Type | Thermal conductivity W/m.K |
|---|---|
| Clay bricks | 0.6-1.0 |
| Cement blocks | 1.2 |



It can be seen that, bottom ash blocks have better thermal properties when compared with good quality building blocks in the market.

### 4.3.3 Drying shrinkage and wetting expansion of blocks

Drying shrinkage and wetting expansion of bottom ash blocks were tested in NBRO laboratories as per SLS 855 and the results are presented in Table 4-21:

Table 4-21: Test results of drying shrinkage and wetting expansion

| Mix by volume | Drying shrinkage (%) | Wetting expansion (%) |
|---|---|---|
| 1:3 | 0.05 | 0.07 |
| 1:6 | 0.04 | 0.03 |

SLS 855 specifies limits for drying shrinkage and wetting expansion as 0.06% and 0.03% respectively. Good quality cement blocks tested in the laboratory had drying shrinkage of 0.04% and wetting expansion of 0.07%.

Therefore, blocks with bottom ash satisfy the drying shrinkage requirement but wetting expansion is marginally higher for the 1:3 mix proportions.

## 4.4 Radiological Significance of Bottom Ash Building Blocks for Construction of Dwellings

### 4.4.1 Activity concentration

The activity concentrations (in Bq $kg^{-1}$) of $^{226}Ra$, $^{232}Th$ and $^{40}K$ in the bottom ash, and the bottom ash and river sand blocks analyzed in this study are given in Table 4-23. The typical world averages for $^{226}Ra$, $^{232}Th$ and $^{40}K$ are 50 Bq $kg^{-1}$, 50 Bq $kg^{-1}$ and 500 Bq $kg^{-1}$ respectively *(NEA-OECD, 1979)*. Therefore obtained values of each sample are below the world average values. Table 4-22 compares activity concentration of each sample tested.

Table 4-22: Comparison of activity concentrations of each sample

| Sample | $^{226}Ra$ Bq $kg^{-1}$ | $^{232}Th$Bq $kg^{-1}$ | $^{40}K$ Bq $kg^{-1}$ |
|---|---|---|---|
| Typical world average | 50 | 50 | 500 |
| Bottom Ash | 29±2 | 37 ±3 | 98±7 |
| Bottom Ash Block | 28±2 | 37±3 | 92±6 |
| River Sand Block | 13±1 | 33±2 | 159±9 |



It can be concluded from the overall results in this study that, bottom ash blocks for building construction do not pose a radiological hazard.

## CHAPTER 5

## 5. COST ANALYSIS OF PRODUCTION OF BOTTOM ASH BLOCKS USING CONVENTIONAL CEMENT BLOCK MAKING MACHINE

To calculate production cost of cement-bottom ash blocks, the mix proportion of QBC 1, BC 1, QBC 2, QBC 3 and BC 6 were selected, since most of these mixes are used by cement block manufacturers with quarry dust instead of bottom ash. These mixes satisfied all the required properties as per SLS 855-1:1989.

Table 5-1 gives summary of cost analysis of satisfactory mixes. Details of cost analysis are given in Annexure 3.

Table 5-1: Summary of cost analysis of satisfactory bottom ash blocks

| Mix | Material Quantity required to produce 1000 Nos. of blocks | | | | Other indirect cost such as water and electricity | Cost per block including profit (Rs) |
|---|---|---|---|---|---|---|
| | Cement (No. of 50kg bags) | Quarry dust (Cube) | Bottom ash (Cube) | Crushed rock aggregate (5-10mm graded) (Cube) | | |
| QBC 1 | 33 | 1 | 1 | 1.5 | Rs.2.50 per block | 60.5 |
| BC 1 | 33 | - | 2 | 1.5 | | 52.0 |
| QBC 2 | 41 | 0.6 | 1.8 | 0.9 | | 59.0 |
| QBC 3 | 36 | 0.52 | 1.9 | 0.52 | | 52.0 |
| BC 6 | 24 | - | 2.2 | 1.5 | | 44.0 |



Cost analysis was done by using the information given by more than 5 medium and 2 large scale manufacturers. As per the questionnaire survey, medium scale block producers expect a profit of Rs.5/= per block and the current market price of a normal cement block is in the range of Rs. 55 to 75 per block. According to the calculated cost of bottom ash blocks (in the range of Rs. 44 to 60), the bottom ash blocks can be marketed at lower price (about 20% ) than conventional blocks available in the market.

## CHAPTER 6

# 6. CONCLUSIONS AND RECOMMENDATIONS

1. Properties of Bottom ash from Nuraicholai Power Plant is having useful physical properties which made it amenable to produce light weight blocks with low thermal conductivity.
2. Although some harmful chemicals and heavy metals were present, there was no health risk involved in its use provided that block manufacture is carried out with appropriate safety arrangement. Radioactivity of bottom ash is found to be in the range of normal river sand block and satisfied the OECD requirement.
3. Available test results on the properties of blocks indicate that bottom ash could provide an effective solution to the scarcity of river sand required for the production of cement blocks.
4. Research results indicate that the production and use of bottom ash blocks lead to the following benefits to the industry.



   a. Cost effective production - It was found that the cost of solid block can be reduced by 20% when sand/ quarry dust replaced with bottom ash.
   b. Weight of bottom ash solid block is 12.5% to 25% less than conventional block of same size.
   c. Thermal conductivity of bottom ash mix of 1:5 was found to be 0.54 W/(m.K) which is about 45% of the conventional cement sand blocks.
   d. Thermal comfort can be achieved due to reduction in thermal conductivity of bottom ash blocks.
   e. Ease of production and construction techniques and machinery used in the production of conventional cement blocks could be adopted in the production of bottom ash blocks as well.

**WAY FORWARD AND APPLICATIONS**

1. The promising results given in laboratory trials suggest the need for performing field trials in production and use of bottom ash blocks with suitable industrial collaboration.
2. There is a possibility of further improving the properties of bottom ash blocks by adding suitable doses of mineral additives (such as fly ash) and chemical admixtures to the cement-bottom ash mix used in production. Trials should be carried out to examine the cost effectiveness of such production.
3. In view of the low particle density (light weight properties) and thermal properties of bottom ash, there is a possibility of producing many innovative and useful building materials such as light weight wall panels or blocks or roofing panels with low thermal conductivity.

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# ANNEXURE:

**Annexure 1: Detail test results of sieve analysis of bottom ash samples**

Oven dry weight= 597.0 g
Weight after washing = 549.3g

Table A1-1: Sieve analysis of bottom ash Sample No. 1

| Sieve size (mm) | Mass retained (g) | Cumulative mass retained (g) | % mass passing | Value specified in BS EN 12390 for fine agg. D≤4mm and d=0 |
|---|---|---|---|---|
| 16 | 0 | 0 | 100 | |
| 14 | 20.48 | 20.48 | 96.6 | |
| 10 | 31.93 | 52.41 | 91.2 | -- |
| 8 | 60.46 | 112.87 | 81.1 | 100 |
| 5 | 50.45 | 163.32 | 72.6 | 95-100 |
| 4 | 25.48 | 188.8 | 68.4 | 85-99 |
| 2.8 | 52.18 | 240.98 | 59.6 | -- |
| 2 | 50.13 | 291.11 | 51.2 | -- |
| 1 | 64.32 | 355.43 | 40.5 | -- |
| 0.5 | 37.08 | 392.51 | 34.3 | 5-45 |
| 0.3 | 30.94 | 423.45 | 29.1 | -- |
| 0.15 | 72.91 | 496.36 | 16.9 | -- |
| 0.063 | 49.72 | 546.08 | 8.5 | 0-3 |
| Pan | 50.92 | 597.00 | 0 | -- |

Oven dry weight = 484.1 g
Weight after washing = 436.4 g

Table A1-2: Sieve analysis of bottom ash Sample No. 1 after removing over 8mm particles

| Sieve size (mm) | Mass retained (g) | Cumulative mass retained (g) | % mass passing | Value specified in BS EN 12390 for fine agg. D≤4mm and d=0 |
|---|---|---|---|---|
| 8 | 0 | 0 | 100.0 | 100 |
| 5 | 50.45 | 50.45 | 89.6 | 95-100 |
| 4 | 25.48 | 75.93 | 84.3 | 85-99 |
| 2.8 | 52.18 | 128.11 | 73.5 | -- |
| 2 | 50.13 | 178.24 | 63.2 | -- |
| 1 | 64.49 | 242.73 | 49.9 | -- |
| 0.5 | 36.91 | 279.64 | 42.2 | 5-45 |
| 0.3 | 30.94 | 310.58 | 35.8 | -- |
| 0.15 | 72.91 | 383.49 | 20.8 | -- |
| 0.063 | 49.72 | 433.21 | 10.5 | 0-3 |
| Pan | 50.89 | 484.10 | 0.0 | -- |

Oven dry weight = 843.0 g
Weight after washing = 828.5 g

Table A1-3: Sieve analysis of bottom ash Sample No. 2

| Sieve size (mm) | Mass retained (g) | Cumulative mass retained (g) | % mass passing | Value specified in BS EN 12390 for fine agg. D≤4mm and d=0 |
|---|---|---|---|---|
| 8 | 23.0 | 23.0 | 97.3 | 100 |
| 5 | 28.0 | 51.0 | 94.0 | 95-100 |
| 4 | 22.5 | 73.5 | 91.3 | 85-99 |
| 2.8 | 48.5 | 122.0 | 85.5 | -- |
| 2 | 38.5 | 160.5 | 81.0 | -- |
| 0.5 | 117.0 | 277.5 | 67.1 | 55-100 |
| 0.3 | 64.5 | 342.0 | 59.4 | -- |
| 0.063 | 486.5 | 828.5 | 1.7 | 0-3 |
| Pan | 14.5 | 843.0 | 0.0 | |

Oven dry weight = 800.0 g
Weight after washing = 623.5 g

Table A1-4: Sieve analysis of bottom ash Sample No. 3

| Sieve size (mm) | Mass retained (g) | Cumulative mass retained (g) | % mass passing | Value specified in BS EN 12390 for fine agg. D≤4mm and d=0 |
|---|---|---|---|---|
| 8 | 0.0 | 0.0 | 100.0 | 100 |
| 5 | 8.1 | 8.1 | 99.0 | 95-100 |
| 4 | 4.5 | 12.6 | 98.4 | 85-99 |
| 2.8 | 14.0 | 26.6 | 96.7 | -- |
| 2 | 23.5 | 50.1 | 93.7 | -- |
| 1 | 46.0 | 96.1 | 84.6 | -- |
| 0.5 | 87.1 | 137.2 | 82.9 | 55-100 |
| 0.3 | 42.1 | 179.3 | 77.6 | -- |
| 0.15 | 250.0 | 429.3 | 31.1 | |
| 0.063 | 435.8 | 615.1 | 23.1 | 0-3 |
| Pan | 184.9 | 800.0 | 0.0 | |

Oven dry weight = 1000.5 g
Weight after washing = 837.1

Table A1-5: Sieve analysis of bottom ash Sample No. 4

| Sieve size (mm) | Mass retained (g) | Cumulative mass retained (g) | % mass passing | Value specified in BS EN 12390 for fine agg. D≤4mm and d=0 |
|---|---|---|---|---|
| 8 | 43.0 | 43.0 | 95.7 | 100 |
| 5 | 17.1 | 60.1 | 94.0 | 95-100 |
| 4 | 49.4 | 109.5 | 89.1 | 85-99 |
| 2 | 50.6 | 160.1 | 84.0 | -- |
| 1 | 108.2 | 268.3 | 73.2 | -- |
| 0.5 | 69.9 | 338.2 | 66.2 | 55-100 |
| 0.3 | 143.1 | 411.4 | 58.9 | |
| 0.063 | 425.6 | 837.0 | 16.3 | 0-3 |
| Pan | 163.5 | 1000.5 | 0.0 | |

**Annexure 2: Detail test results of physical properties and comparison of test results (Blocks produced with conventional cement block making machine)**

Table A2-1: Compressive strength test results of solid blocks made with Cement: River sand: Quarry dust = 1:3:3 mix proportion (RQ 1)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 192 | 201.2 | 5.2 |
| 2 | 390 | 100 | 193 | 237.6 | 6.1 |
| 3 | 390 | 100 | 194 | 207.8 | 5.3 |
| 4 | 390 | 100 | 193 | 232.3 | 6.0 |
| | | | Average | | 5.6 |
| | | | Standard deviation | | 0.5 |



Table A2-2: Compressive strength test results of solid blocks made with Cement: Quarry dust : Bottom ash = 1:3:3 mix proportion (QB 1)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 194 | 170.6 | 4.4 |
| 2 | 390 | 100 | 194 | 180.5 | 4.6 |
| 3 | 390 | 100 | 198 | 183.2 | 4.7 |
| 4 | 390 | 100 | 198 | 106.6 | 2.7 |
| | | | Average | | 4.1 |
| | | | Standard deviation | | 0.9 |

Table A2-3: T-Analysis of Compressive strength test results of solid blocks made with Cement: River sand: Quarry dust = 1:3:3 and Cement: Quarry dust: Bottom ash: =1:3:3 Mix proportion

| Source of Variation | Compressive strength (N/mm2) | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQ 1 | 5.6 | 0.5 | 6 | 1.174 | 2.447 |
| QB 1 | 4.1 | 0.9 | | | |

Comment: Based on Student T-distribution there is no significant difference at 95% confident level in between compressive strength of blocks produced with mix Cement: River sand: Quarry dust = 1:3:3 and Cement: Quarry dust: Bottom ash: =1:3:3 Mix proportion



Table A2-4: Density test results of solid blocks made with Cement: River sand: Quarry dust= 1:3:3 mix proportion (RQ 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 14922 | 14259 | 15848 | 8328 | 1896 |
| 2 | 14999 | 14224 | 15817 | 8316 | 1896 |
| 3 | 15241 | 14441 | 15981 | 8443 | 1916 |
| 4 | 15204 | 14669 | 16054 | 8513 | 1945 |
| | | | Average | | 1913 |
| | | | Standard deviation | | 23.2 |

Table A2-5: Density test results of solid blocks made with Cement: Quarry dust: Bottom ash = 1:3:3 mix proportion (QB 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 12023 | 10993 | 13176 | 5743 | 1479 |
| 2 | 12139 | 11009 | 13167 | 5768 | 1488 |
| 3 | 12671 | 11529 | 13708 | 6155 | 1526 |
| 4 | 12266 | 11250 | 13380 | 5930 | 1510 |
| | | | Average | | 1501 |
| | | | Standard deviation | | 21.5 |

Table A2-6: T-Analysis of density test results of solid blocks made with Cement: River sand: Quarry dust = 1:3:3 and Cement: Quarry dust: Bottom ash: =1:3:3 Mix proportion



| Source of Variation | Density $kg/m^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQ 1 | 1913.4 | 23.2 | 6 | 57.427 | 2.447 |
| QB 1 | 1500.8 | 21.5 | | | |

Comment: Based on Student T-distribution there is a significant difference at 95% confident level in between density of blocks produced with Cement: River sand: Quarry dust = 1:3:3 and Cement: Quarry dust: Bottom ash: =1:3:3 Mix proportion

The density of blocks made with cement, bottom ash and quarry dust is 78% of blocks made with cement, river sand and quarry dust.

Table A2-7: Water absorption results of solid blocks made with Cement: River sand: Quarry dust= 1:3:3 mix proportion (RQ 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 14922 | 14259 | 15848 | 8328 | 211 |
| 2 | 14999 | 14224 | 15817 | 8316 | 212 |
| 3 | 15241 | 14441 | 15981 | 8443 | 204 |
| 4 | 15204 | 14669 | 16054 | 8513 | 184 |
| | | | Average | | 203 |
| | | | Standard deviation | | 13.3 |

Table A2-8: Water absorption of solid blocks made with Cement: Quarry dust: Bottom ash = 1:3:3 mix proportion (QB 1)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12023 | 10993 | 13176 | 5743 | 294 |
| 2 | 12139 | 11009 | 13167 | 5768 | 292 |
| 3 | 12671 | 11529 | 13708 | 6155 | 288 |
| 4 | 12266 | 11250 | 13380 | 5930 | 286 |
| | | | Average | | 290 |
| | | | Standard deviation | | 3.4 |

Table A2-9: T-Analysis of water absorption test results of solid blocks made with Cement: River sand: Quarry dust = 1:3:3 and Cement: Quarry dust: Bottom ash: =1:3:3 Mix proportion

| Source of Variation | Water absorption kg/m$^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQ 1 | 202.9 | 13.3 | 6 | -18.362 | 2.447 |
| QB 1 | 289.9 | 3.4 | | | |

Comment: There is a significant difference at 95% confident level in between water absorption of blocks produced with Cement: River sand: Quarry dust = 1:3:3 and Cement: Quarry dust: Bottom ash: =1:3:3 Mix proportion. The water absorption of blocks made with cement, bottom ash and quarry dust is 143% of blocks made with cement, river sand and quarry dust and it exceeded the limit specified in SLS 855.



Table A2-10: Compressive strength test results of solid blocks made with Cement: River sand: Quarry dust: Crushed rock aggregate = 1:2:2:3 mix proportion (RQC 1)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 192 | 297.1 | 7.6 |
| 2 | 390 | 100 | 193 | 390.5 | 10.0 |
| 3 | 390 | 100 | 194 | 340.5 | 8.7 |
| 4 | 390 | 100 | 193 | 338.2 | 8.7 |
| | | | Average | | 8.8 |
| | | | Standard deviation | | 1.0 |

Table A2-11: Compressive strength test results of solid blocks made with Cement: Quarry dust: Bottom ash: Crushed rock aggregate= 1:2:2:3 mix proportion (QBC 1)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength ($N/mm^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 225.7 | 5.8 |
| 2 | 390 | 100 | 190 | 270.2 | 6.9 |
| 3 | 390 | 100 | 190 | 260.6 | 6.7 |
| 4 | 390 | 100 | 190 | 245.3 | 6.3 |
| | | | Average | | 6.4 |
| | | | Standard deviation | | 0.5 |

Table A2-12: T-Analysis of Compressive strength test results of solid blocks made with Cement: River sand: Quarry dust: Crushed rock aggregate= 1:2:2:3 and Cement: Quarry dust: Bottom ash: Crushed rock aggregate 1:2:2:3 Mix proportion



| Source of Variation | Water absorption kg/m$^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQC 1 | 8.8 | 1.0 | 6 | 1.744 | 2.447 |
| QBC 1 | 6.4 | 0.5 | | | |

Comment: There is no significance difference at 95% confident level in between compressive strength of blocks produced with mix Cement: River sand: Quarry dust: Crushed rock aggregate= 1:2:2:3 and Cement: Quarry dust: Bottom ash: Crushed rock aggregate 1:2:2:3 Mix proportion.

Table A2-13: Density test results of solid blocks made with Cement: River Sand: Quarry Dust: Crushed rock aggregate= 1:2:2:3 mix proportion (RQC 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 17316 | 17245 | 17916 | 10143 | 2219 |
| 2 | 17008 | 16917 | 17604 | 9947 | 2209 |
| 3 | 17023 | 16932 | 17620 | 9962 | 2211 |
| 4 | 17300 | 17232 | 17902 | 10129 | 2217 |
| | | | Average | | 2214 |
| | | | Standard deviation | | 4.5 |

Table A2-14: Density test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:2:2:3 mix proportion (QBC 1)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 14929 | 14652 | 15797 | 8258 | 1943 |
| 2 | 15256 | 14992 | 16010 | 8411 | 1973 |
| 3 | 15245 | 14980 | 16001 | 8400 | 1971 |
| 4 | 14940 | 14664 | 15806 | 8269 | 1946 |
| | | | Average | | 1958 |
| | | | Standard deviation | | 15.8 |

Table A2-15: T-Analysis of density test results of solid blocks made with Cement: River sand: Quarry dust: Crushed rock aggregate= 1:2:2:3 and Cement: Quarry dust: Bottom ash: Crushed rock aggregate 1:2:2:3 Mix proportion

| Source of Variation | Density kg/m$^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQC 1 | 2214.0 | 4.5 | 6 | 49.387 | 2.447 |
| QBC 1 | 1958.2 | 15.8 | | | |

Comment: There is a significant difference at 95% confident level in between density of blocks produced with mix Cement: River sand: Quarry dust: Crushed rock aggregate= 1:2:2:3 and Cement: Quarry dust: Bottom ash: Crushed rock aggregate 1:2:2:3 Mix proportion

The density of blocks made with cement, quarry dust, bottom ash, and Crushed rock aggregate is 88% of blocks made with cement, river sand, quarry dust and Crushed rock aggregate.



Table A2-16: Water absorption results of solid blocks made with Cement: River Sand: Quarry Dust: Crushed rock aggregate= 1:2:2:3 mix proportion (RQC 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 17316 | 17245 | 17916 | 10143 | 86 |
| 2 | 17008 | 16917 | 17604 | 9947 | 90 |
| 3 | 17023 | 16932 | 17620 | 9962 | 90 |
| 4 | 17300 | 17232 | 17902 | 10129 | 86 |
| | | | Average | | 88 |
| | | | Standard deviation | | 2.0 |

Table A2-17: Water absorption of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:2:2:3 mix proportion (QBC 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 14929 | 14652 | 15797 | 8258 | 152 |
| 2 | 15256 | 14992 | 16010 | 8411 | 134 |
| 3 | 15245 | 14980 | 16001 | 8400 | 134 |
| 4 | 14940 | 14664 | 15806 | 8269 | 152 |
| | | | Average | | 143 |
| | | | Standard deviation | | 10.1 |



Table A2-18: T-Analysis of water absorption test results of solid blocks made with Cement: River sand: Quarry dust: Crushed rock aggregate= 1:2:2:3 and Cement: Quarry dust: Bottom ash: Crushed rock aggregate 1:2:2:3 Mix proportion

| Source of Variation | Water absorption kg/m$^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQC 1 | 88.0 | 2.0 | 6 | -13.361 | 2.447 |
| QBC 1 | 142.9 | 10.1 | | | |

Comment: There is a significant difference at 95% confident level in between water absorption of blocks produced with Cement: River sand: Quarry dust: Crushed rock aggregate= 1:2:2:3 and Cement: Quarry dust: Bottom ash: Crushed rock aggregate 1:2:2:3 Mix proportion. The water absorption of blocks made with cement, bottom ash and quarry dust is 143% of blocks made with cement, river sand and quarry dust and it exceeded the limit specified in SLS 855.

Table A2-19: Compressive strength test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:4:3 mix proportion (BC 1)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 156.1 | 4.0 |
| 2 | 390 | 100 | 190 | 204.1 | 5.2 |
| 3 | 390 | 100 | 190 | 173.2 | 4.4 |
| 4 | 390 | 100 | 190 | 186.1 | 4.8 |
| | | | Average | | 4.6 |
| | | | Standard deviation | | 0.5 |

Table A2-20: Compressive strength test results of solid blocks made with Cement: Quarry Dust: Crushed rock aggregate= 1:4:3 mix proportion (QC 1)



| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 311.6 | 8.0 |
| 2 | 390 | 100 | 190 | 401.8 | 10.3 |
| 3 | 390 | 100 | 190 | 242.2 | 6.2 |
| 4 | 390 | 100 | 190 | 456.8 | 11.7 |
| | | | Average | | 9.1 |
| | | | Standard deviation | | 2.4 |

Table A2-21: T-Analysis of Compressive strength test results of solid blocks made with Cement: Quarry Dust: Crushed rock aggregate= 1:4:3 and Cement: Quarry Dust: Crushed rock aggregate= 1:4:3 Mix proportion

| Source of Variation | Compressive strength (N/mm2) | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| BC 1 | 4.6 | 0.5 | 6 | 2.201 | 2.447 |
| QC 1 | 9.1 | 2.4 | | | |

Comment: There is no significant difference at 95% confident level in between compressive strength of blocks produced with mix Cement: Bottom Ash: Crushed rock aggregate= 1:4:3 and Cement: Quarry Dust: Crushed rock aggregate= 1:4:3 Mix proportion.



Table A2-22: Density test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate = 1:4:3 mix proportion (BC 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 13237 | 13001 | 14183 | 6635 | 1722 |
| 2 | 13124 | 12906 | 14093 | 6500 | 1700 |
| 3 | 13025 | 12730 | 14026 | 6541 | 1701 |
| 4 | 12843 | 12714 | 14100 | 6531 | 1680 |
| | | | Average | | 1701 |
| | | | Standard deviation | | 17.4 |

Table A2-13: Water absorption test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:4:3 mix proportion (BC 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 13237 | 13001 | 14183 | 6635 | 157 |
| 2 | 13124 | 12906 | 14093 | 6500 | 156 |
| 3 | 13025 | 12730 | 14026 | 6541 | 173 |
| 4 | 12843 | 12714 | 14100 | 6531 | 183 |
| | | | Average | | 167 |
| | | | Standard deviation | | 13.2 |

Comment: The density and water absorption of blocks made with cement, bottom ash and Crushed rock aggregate are given above. Comparison was not carried out, since same pattern of earlier results continued.



Table A2-24: Compressive strength test results of solid blocks made with Cement: Quarry dust: Bottom Ash = 1:4:3 mix proportion (QB 1)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength ($N/mm^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 153.4 | 3.9 |
| 2 | 390 | 100 | 190 | 150.4 | 3.9 |
| 3 | 390 | 100 | 190 | 150.2 | 3.9 |
| 4 | 390 | 100 | 190 | 154.1 | 4.0 |
| | | | Average | | 3.9 |
| | | | Standard deviation | | 0.1 |

Table A2-25: Density test results of solid blocks made with Cement: Quarry dust: Bottom Ash = 1:4:3 mix proportion (QB 1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12241 | 11766 | 12870 | 5590 | 1616 |
| 2 | 12540 | 12053 | 12900 | 5620 | 1656 |
| 3 | 12320 | 11839 | 12680 | 5401 | 1626 |
| 4 | 12187 | 11789 | 12799 | 5631 | 1645 |
| | | | Average | | 1636 |
| | | | Standard deviation | | 17.7 |

Table A2-26: Water absorption test results of solid blocks made with Cement: Quarry dust: Bottom Ash = 1:4:3 mix proportion (QB 1)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12241 | 11766 | 12870 | 5590 | 152 |
| 2 | 12540 | 12053 | 12900 | 5620 | 116 |
| 3 | 12320 | 11839 | 12680 | 5401 | 116 |
| 4 | 12187 | 11789 | 12799 | 5631 | 141 |
| | | | Average | | 131 |
| | | | Standard deviation | | 18.1 |

Comment: The density and water absorption of blocks made with cement, bottom ash and Crushed rock aggregate are given above. Comparison was not carried out, since the same pattern of earlier results continued.

Table A2-27: Compressive strength test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:3:1:1.5 mix proportion (QBC 2)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength ($N/mm^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 224.7 | 5.8 |
| 2 | 390 | 100 | 190 | 181.0 | 4.6 |
| 3 | 390 | 100 | 190 | 200.8 | 5.1 |
| 4 | 390 | 100 | 190 | 200.4 | 5.1 |
| | | | Average | | 5.2 |
| | | | Standard deviation | | 0.5 |



Table A2-28: Density test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:3:1:1.5 mix proportion (QBC 2)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 13310 | 13146 | 14251 | 6971 | 1806 |
| 2 | 13095 | 12992 | 14077 | 6894 | 1809 |
| 3 | 13290 | 13120 | 14239 | 6960 | 1802 |
| 4 | 13320 | 13164 | 14260 | 6988 | 1810 |
| | | | Average | | 1807 |
| | | | Standard deviation | | 3.4 |

Table A2-29: Water absorption of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:3:1:1.5 mix proportion (QBC 2)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 13310 | 13146 | 14251 | 6971 | 152 |
| 2 | 13095 | 12992 | 14077 | 6894 | 151 |
| 3 | 13290 | 13120 | 14239 | 6960 | 154 |
| 4 | 13320 | 13164 | 14260 | 6988 | 151 |
| | | | Average | | 152 |
| | | | Standard deviation | | 1.3 |

Comment: Control mix was not prepared to this mix proportion. Compressive strength and water absorption are within the limit specified in SLS 855.Density results satisfied the limit specified in SLS 855. Comments on light weight property cannot be made for this mix, since a control mix was not prepared.



Table A2-3: Compressive strength test results of solid blocks made with Cement: Bottom Ash= 1:7 mix proportion (B1)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 41.5 | 1.1 |
| 2 | 390 | 100 | 190 | 48.5 | 1.2 |
| 3 | 390 | 100 | 190 | 44.8 | 1.1 |
| 4 | 390 | 100 | 190 | 45.2 | 1.2 |
| | | | Average | | 1.2 |
| | | | Standard deviation | | 0.1 |

Table A2-4: Density test results of solid blocks made with Cement: Bottom Ash = 1:7 mix proportion (B1)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 8443 | 7766 | 10315 | 3310 | 1109 |
| 2 | 8703 | 7950 | 10285 | 3338 | 1144 |
| 3 | 8603 | 7850 | 10180 | 3218 | 1128 |
| 4 | 8547 | 7860 | 10408 | 3430 | 1126 |
| | | | Average | | 1127 |
| | | | Standard deviation | | 14.6 |

Table A2-52: Water absorption of solid blocks made with Cement: Bottom Ash= 1:7 mix proportion (B1)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 8443 | 7766 | 10315 | 3310 | 364 |
| 2 | 8703 | 7950 | 10285 | 3338 | 336 |
| 3 | 8603 | 7850 | 10180 | 3218 | 335 |
| 4 | 8547 | 7860 | 10408 | 3430 | 365 |
| | | | Average | | 350 |
| | | | Standard deviation | | 16.8 |

Comment: Control mix was not prepared to this mix proportion. Compressive strength was within the limit specified in SLS 855.Water absorption exceeded the limits specified in SLS 855. Density results satisfied the limit specified in SLS 855.

Comments cannot be made on light weight property of this mix, since a control mix was not prepared.

Table A2-63: Compressive strength test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:3.5:2:1 mix proportion(QBC 3)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength ($N/mm^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 166.5 | 4.3 |
| 2 | 390 | 100 | 190 | 160.5 | 4.1 |
| 3 | 390 | 100 | 190 | 163.5 | 4.2 |
| 4 | 390 | 100 | 190 | 162.5 | 4.2 |
| | | | Average | | 4.2 |
| | | | Standard deviation | | 0.1 |



Table A2-74: Density test results of solid blocks made with Cement: Bottom Ash: Quarry Dust: Crushed rock aggregate= 1:3.5:2:1 mix proportion (QBC 3)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 13287 | 12569 | 13310 | 6265 | 1784 |
| 2 | 13159 | 12424 | 13266 | 6250 | 1771 |
| 3 | 13205 | 12470 | 13306 | 6301 | 1780 |
| 4 | 13230 | 12471 | 13302 | 6273 | 1774 |
| | | | Average | | 1777 |
| | | | Standard deviation | | 5.9 |

Table A2-35: Water absorption of solid blocks made with Cement: Bottom Ash: Quarry Dust: Crushed rock aggregate= 1:3.5:2:1 mix proportion (QBC 3)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 13287 | 12569 | 13310 | 6265 | 105 |
| 2 | 13159 | 12424 | 13266 | 6250 | 120 |
| 3 | 13205 | 12470 | 13306 | 6301 | 119 |
| 4 | 13230 | 12471 | 13302 | 6273 | 118 |
| | | | Average | | 116 |
| | | | Standard deviation | | 7.0 |

Comment: Compressive strength, density and water absorption were within the limits specified in SLS 855. Comments on light weight property cannot be made, since a control mix was not prepared.



Table A2-8: Compressive strength test results of solid blocks made with Cement: Quarry Dust: Crushed rock aggregate = 1:12:8 mix proportion (QC 2)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 194 | 49.5 | 1.3 |
| 2 | 390 | 100 | 194 | 47.5 | 1.2 |
| 3 | 390 | 100 | 198 | 49.0 | 1.3 |
| 4 | 390 | 100 | 198 | 48.0 | 1.2 |
| | | | Average | | 1.2 |
| | | | Standard deviation | | 0.0 |

Table A2-37: Compressive strength test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion (BC 2)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 192 | 58.6 | 1.5 |
| 2 | 390 | 100 | 193 | 59.6 | 1.5 |
| 3 | 390 | 100 | 194 | 59.0 | 1.5 |
| 4 | 390 | 100 | 193 | 59.2 | 1.5 |
| | | | Average | | 1.5 |
| | | | Standard deviation | | 0.0 |

Table A2-38: T-Analysis of Compressive strength test results of solid blocks made with Cement: Quarry Dust: Crushed rock aggregate =1:12:8 and Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion



| Source of Variation | Compressive strength (N/mm2) | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| QC 2 | 1.2 | 0.0 | 6 | 1.321 | 2.447 |
| BC 2 | 1.5 | 0.0 | | | |

Comment: Based on Student T-distribution there is no significant difference at 95% confident level in between compressive strength of blocks produced with mix Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 and Cement: Quarry Dust: Crushed rock aggregate =1:12:8.

Table A2-39: Density test results of solid blocks made with Cement: Quarry Dust: Crushed rock aggregate = 1:12:8 mix proportion (QC 2)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 15638 | 15000 | 16292 | 8981 | 2052 |
| 2 | 15817 | 15235 | 16560 | 9130 | 2050 |
| 3 | 15730 | 15100 | 16390 | 9095 | 2070 |
| 4 | 15631 | 15076 | 16454 | 9029 | 2030 |
| | | | Average | | 2051 |
| | | | Standard deviation | | 16.1 |

Table A2-40: Density test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion (BC 2)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 15771 | 15214 | 16550 | 9130 | 2050 |
| 2 | 15518 | 14941 | 16280 | 8980 | 2047 |
| 3 | 15674 | 15116 | 16453 | 9034 | 2037 |
| 4 | 15617 | 15080 | 16385 | 9074 | 2063 |
| | | | Average | | 2049 |
| | | | Standard deviation | | 10.4 |

Table A2-41: T-Analysis of density test results of solid blocks made with Cement: Quarry Dust: Crushed rock aggregate = 1:12:8 and Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion

| Source of Variation | Density kg/m$^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| QC 2 | 2050.6 | 16.1 | 6 | -0.236 | 2.447 |
| BC 2 | 2049.3 | 10.4 | | | |

Comment: Based on Student T-distribution there is no significant difference at 95% confident level in between density of blocks produced with mix Cement: Quarry Dust: Crushed rock aggregate = 1:12:8 and Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion.

Table A2-92: Water absorption of solid blocks made Cement: Quarry Dust: Crushed rock aggregate = 1:12:8 mix proportion (QC 2)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 15638 | 15000 | 16292 | 8981 | 177 |
| 2 | 15817 | 15235 | 16560 | 9130 | 178 |
| 3 | 15730 | 15100 | 16390 | 9095 | 177 |
| 4 | 15631 | 15076 | 16454 | 9029 | 186 |
| | | | Average | | 179 |
| | | | Standard deviation | | 4.2 |

Table A2-103: Water absorption results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion (BC 2)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 15771 | 15214 | 16550 | 9130 | 180 |
| 2 | 15518 | 14941 | 16280 | 8980 | 183 |
| 3 | 15674 | 15116 | 16453 | 9034 | 180 |
| 4 | 15617 | 15080 | 16385 | 9074 | 178 |
| | | | Average | | 181 |
| | | | Standard deviation | | 2.1 |



Table A2-44: T-Analysis of water absorption test results of solid blocks made with Cement: Quarry Dust: Crushed rock aggregate = 1:12:8 and Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion

| Source of Variation | Water absorption kg/m$^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| Mix 1 | 179.4 | 4.2 | 6 | 0.426 | 2.447 |
| Mix2 | 180.5 | 2.1 | | | |

Comment: Based on Student T-distribution there is no significant difference at 95% confident level in between water absorption of blocks produced with mix Cement: Quarry Dust: Crushed rock aggregate = 1:12:8 and Cement: Bottom Ash: Crushed rock aggregate = 1:12:8 mix proportion

Table A2-45: Compressive strength test results of solid blocks made with Cement: River sand: Quarry dust = 1:4:5 mix proportion (RQ 2)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 192 | 180.0 | 4.6 |
| 2 | 390 | 100 | 193 | 195.0 | 5.0 |
| 3 | 390 | 100 | 194 | 144.0 | 3.7 |
| 4 | 390 | 100 | 193 | 135.0 | 3.5 |
| | | | Average | | 4.2 |
| | | | Standard deviation | | 0.7 |



Table A2-4611: Compressive strength test results of solid blocks made with Cement: Quarry dust: Bottom ash= 1:4:5 mix proportion (QB 2)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 194 | 135.3 | 3.5 |
| 2 | 390 | 100 | 194 | 134.0 | 3.4 |
| 3 | 390 | 100 | 198 | 134.2 | 3.4 |
| 4 | 390 | 100 | 198 | 142.0 | 3.6 |
| | | | Average | | 3.5 |
| | | | Standard deviation | | 0.1 |

Table A2-47: T-Analysis of Compressive strength test results of solid blocks made with Cement: River Sand: Quarry Dust = 1:4:5 and Cement: Quarry dust: Bottom ash= 1:4:5 Mix proportion

| Source of Variation | Compressive strength (N/mm2) | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQ 2 | 4.2 | 0.7 | 6 | 0.633 | 2.447 |
| QB 2 | 3.5 | 0.1 | | | |

Comment: Based on Student T-distribution there is no significant difference at 95% confident level in between compressive strength of blocks produced with mix with Cement: River Sand: Quarry Dust = 1:4:5 and Cement: Quarry dust: Bottom ash= 1:4:5 Mix proportion



Table A2-48: Density test results of solid blocks made with Cement: River sand: Quarry dust = 1:4:5 mix proportion (RQ 2)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 15803 | 15012 | 16455 | 8740 | 1946 |
| 2 | 16018 | 15182 | 16622 | 8875 | 1960 |
| 3 | 15910 | 15116 | 16560 | 8860 | 1963 |
| 4 | 15913 | 15083 | 16512 | 8756 | 1945 |
| | | | Average | | 1953 |
| | | | Standard deviation | | 9.4 |

Table A2-49: Density test results of solid blocks made with Cement: Quarry dust: Bottom ash= 1:4:5 mix proportion (QB 2)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 12574 | 11085 | 13335 | 5965 | 1504 |
| 2 | 12595 | 11054 | 13305 | 5930 | 1499 |
| 3 | 12506 | 10956 | 13216 | 5853 | 1488 |
| 4 | 12653 | 11132 | 13398 | 6050 | 1515 |
| | | | Average | | 1501 |
| | | | Standard deviation | | 11.2 |

Table A2-120: T-Analysis of density test results of solid blocks made with Cement: River Sand: Quarry Dust = 1:4:5 and Cement: Quarry dust: Bottom ash= 1:4:5 Mix proportion



| Source of Variation | Density $kg/m^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQ 2 | 1953.3 | 9.4 | | | |
| QB 2 | 1501.5 | 11.2 | 6 | 92.322 | 2.447 |

Comment: Based on Student T-distribution there is a significant difference at 95% confident level in between density of blocks produced with Cement: River Sand: Quarry Dust = 1:4:5 and Cement: Quarry dust: Bottom ash= 1:4:5 Mix proportion. The density of blocks made with cement, bottom ash and quarry dust was 77% of blocks made with cement, river sand and quarry dust.

Table A2-131: Water absorption results of solid blocks made with Cement: River Sand: Quarry Dust= 1:4:5 mix proportion (RQ 2)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 15803 | 15012 | 16455 | 8740 | 187 |
| 2 | 16018 | 15182 | 16622 | 8875 | 186 |
| 3 | 15910 | 15116 | 16560 | 8860 | 188 |
| 4 | 15913 | 15083 | 16512 | 8756 | 184 |
| | | | Average | | 186 |
| | | | Standard deviation | | 1.5 |

Table A2-142: Water absorption of solid blocks made with Cement: Quarry dust: Bottom ash= 1:4:5 mix proportion (QB 2)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12574 | 11085 | 13335 | 5965 | 305 |
| 2 | 12595 | 11054 | 13305 | 5930 | 305 |
| 3 | 12506 | 10956 | 13216 | 5853 | 307 |
| 4 | 12653 | 11132 | 13398 | 6050 | 308 |
| | | | Average | | 306 |
| | | | Standard deviation | | 1.5 |

Table A2-153: T-Analysis of water absorption test results of solid blocks made with Cement: River Sand: Quarry Dust = 1:4:5 and Cement: Quarry Dust: Bottom Ash = 1:4:5 Mix proportion

| Source of Variation | Water absorption kg/m$^3$ | | Degree of freedom | t-value computed | t-value at 0.05 level of significance |
|---|---|---|---|---|---|
| | Average | Standard Deviation | | | |
| RQ 2 | 186.2 | 1.5 | 6 | -64.950 | 2.447 |
| QB 2 | 306.5 | 1.5 | | | |

Comment: Based on Student T-distribution there is a significant difference at 95% confident level in between water absorption of blocks produced with mix Cement: River Sand: Quarry Dust = 1:4:5 and Cement: Quarry Dust: Bottom Ash = 1:4:5 Mix proportion. The water absorption of blocks made with cement, bottom ash and quarry dust is 165% of blocks made with cement, river sand and quarry dust and it exceeded the limit specified in SLS 855.



Table A2-164: Compressive strength test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:7:3 mix proportion (BC 3)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 90 | 2.3 |
| 2 | 390 | 100 | 190 | 101 | 2.6 |
| 3 | 390 | 100 | 190 | 84 | 2.2 |
| 4 | 390 | 100 | 190 | 89 | 2.3 |
| | | | Average | | 2.3 |
| | | | Standard deviation | | 0.2 |

Table A2-55: Density test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:7:3 mix proportion (BC 3)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12433 | 11263 | 13515 | 5968 | 1492 |
| 2 | 12686 | 10970 | 13175 | 5940 | 1516 |
| 3 | 12767 | 11226 | 13400 | 5930 | 1503 |
| 4 | 11884 | 10862 | 13030 | 5710 | 1484 |
| | | | Average | | 1499 |
| | | | Standard deviation | | 14.0 |

Table A2-56: Water absorption of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:7:3 mix proportion (BC 3)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12433 | 11263 | 13515 | 5968 | 298 |
| 2 | 12686 | 10970 | 13175 | 5940 | 305 |
| 3 | 12767 | 11226 | 13400 | 5930 | 291 |
| 4 | 11884 | 10862 | 13030 | 5710 | 296 |
| | | | Average | | 298 |
| | | | Standard deviation | | 5.7 |

Comment: Control mix was not prepared to this mix proportion. Compressive strength results satisfied the limit specified in SLS 855.

Comments cannot be made on light weight property of this mix, since a control mix was not prepared. Water absorption of this mix exceeded the limit specified in SLS.

Table A2-5717: Compressive strength test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:14:6 mix proportion (BC 4)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 40 | 1.0 |
| 2 | 390 | 100 | 190 | 39 | 1.0 |
| 3 | 390 | 100 | 190 | 34 | 0.9 |
| 4 | 390 | 100 | 190 | 39 | 1.0 |
| | | | Average | | 1.0 |
| | | | Standard deviation | | 0.1 |



Table A2-5818: Density test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:14:6 mix proportion (BC 4)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 11002 | 9623 | 11955 | 4910 | 1366 |
| 2 | 10337 | 9553 | 11870 | 4900 | 1371 |
| 3 | 11201 | 10022 | 12380 | 5180 | 1392 |
| 4 | 10997 | 10254 | 12562 | 5300 | 1412 |
| | | | Average | | 1385 |
| | | | Standard deviation | | 21.2 |

Table A2-59: Water absorption of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:14:6 mix proportion (BC 4)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 11002 | 9623 | 11955 | 4910 | 331 |
| 2 | 10337 | 9553 | 11870 | 4900 | 332 |
| 3 | 11201 | 10022 | 12380 | 5180 | 328 |
| 4 | 10997 | 10254 | 12562 | 5300 | 318 |
| | | | Average | | 327 |
| | | | Standard deviation | | 6.6 |

Comment: Control mix was not prepared to this mix proportion. Compressive strength results do not satisfy the limit specified in SLS 855. Comments cannot be made on light weight property of this mix, since a control mix was not prepared. Water absorption of this mix exceeded the limit specified in SLS.



Table A2-60: Compressive strength test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:9:4 mix proportion (BC 5)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 51 | 1.3 |
| 2 | 390 | 100 | 190 | 51 | 1.3 |
| 3 | 390 | 100 | 190 | 62 | 1.6 |
| 4 | 390 | 100 | 190 | 78 | 2.0 |
| | | | Average | | 1.6 |
| | | | Standard deviation | | 0.3 |

Comment: Control mix was not prepared to this mix proportion. Compressive strength results satisfy the limit specified in SLS 855. Water absorption and density were not tested.

Table A2-191: Compressive strength test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:2:6:2 mix proportion (QBC 4)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength ($N/mm^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 81 | 2.1 |
| 2 | 390 | 100 | 190 | 79 | 2.0 |
| 3 | 390 | 100 | 190 | 82 | 2.1 |
| 4 | 390 | 100 | 190 | 70 | 1.8 |
| | | | Average | | 2.0 |
| | | | Standard deviation | | 0.1 |



Table A2-202: Density test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:2:6:2 mix proportion (QBC 4)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density $kg/m^3$ |
|---|---|---|---|---|---|
| 1 | 11405 | 10769 | 12853 | 5450 | 1455 |
| 2 | 11307 | 10650 | 12850 | 5499 | 1449 |
| 3 | 11135 | 10675 | 12997 | 5496 | 1423 |
| 4 | 11300 | 10632 | 12842 | 5469 | 1442 |
| | | | Average | | 1442 |
| | | | Standard deviation | | 13.7 |

Table A2-213: Water absorption of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:2:6:2 mix proportion (QBC 4)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 11405 | 10769 | 12853 | 5450 | 282 |
| 2 | 11307 | 10650 | 12850 | 5499 | 299 |
| 3 | 11135 | 10675 | 12997 | 5496 | 310 |
| 4 | 11300 | 10632 | 12842 | 5469 | 300 |
| | | | Average | | 298 |
| | | | Standard deviation | | 11.7 |

Comment: Control mix was not prepared to this mix proportion. Compressive strength satisfied the limit specified in SLS 855.Water absorption exceeded the limits specified in SLS 855. Comments cannot be made on light weight property of this mix, since a control mix was not prepared.



Table A2-224: Compressive strength test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate=1:4:12:4 mix proportion(QBC 5)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 31 | 0.8 |
| 2 | 390 | 100 | 190 | 30 | 0.8 |
| 3 | 390 | 100 | 190 | 23 | 0.6 |
| 4 | 390 | 100 | 190 | 35 | 0.9 |
| | | | Average | | 0.8 |
| | | | Standard deviation | | 0.1 |

Table A2-65: Density test results of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:4:12:4 mix proportion (QBC 5)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 11162 | 10694 | 12887 | 5427 | 1434 |
| 2 | 11268 | 10839 | 12946 | 5479 | 1452 |
| 3 | 11250 | 10729 | 12995 | 5438 | 1420 |
| 4 | 11254 | 10804 | 12963 | 5434 | 1435 |
| | | | Average | | 1435 |
| | | | Standard deviation | | 13.0 |

Table A2-66: Water absorption of solid blocks made with Cement: Quarry Dust: Bottom Ash: Crushed rock aggregate= 1:4:12:4 mix proportion (QBC 5)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 11405 | 10769 | 12853 | 5450 | 282 |
| 2 | 11307 | 10650 | 12850 | 5499 | 299 |
| 3 | 11135 | 10675 | 12997 | 5496 | 310 |
| 4 | 11300 | 10632 | 12842 | 5469 | 300 |
| | | | Average | | 298 |
| | | | Standard deviation | | 11.7 |

Comment: Control mix was not prepared to this mix proportion. Compressive strength and water absorption do not satisfy the limits specified in SLS 855.Comments cannot be made on light weight property of this mix, since a control mix was not prepared.

Table A2-67: Compressive strength test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:6:4 mix proportion (BC 6)

| Serial No. | Length (mm) | Width (mm) | Height (mm) | Maximum Failure Load (kN) | Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|---|
| 1 | 390 | 100 | 190 | 94.0 | 2.4 |
| 2 | 390 | 100 | 190 | 119.0 | 3.1 |
| 3 | 390 | 100 | 190 | 103.0 | 2.6 |
| 4 | 390 | 100 | 190 | 95.0 | 2.4 |
| 5 | 390 | 100 | 190 | 88.5 | 2.3 |
| 6 | 390 | 100 | 190 | 118.0 | 3.0 |
| 7 | 390 | 100 | 190 | 89.5 | 2.3 |
| 8 | 390 | 100 | 190 | 136.0 | 3.5 |
| 9 | 390 | 100 | 190 | 100.5 | 2.6 |
| 10 | 390 | 100 | 190 | 81.0 | 2.1 |
| 11 | 390 | 100 | 190 | 92.0 | 2.4 |
| 12 | 390 | 100 | 190 | 101.5 | 2.6 |
| 13 | 390 | 100 | 190 | 114.0 | 2.9 |
| 14 | 390 | 100 | 190 | 116.0 | 3.0 |
| 15 | 390 | 100 | 190 | 90.5 | 2.3 |
| 16 | 390 | 100 | 190 | 122.0 | 3.1 |
| 17 | 390 | 100 | 190 | 96.0 | 2.5 |
| 18 | 390 | 100 | 190 | 115.0 | 2.9 |
| 19 | 390 | 100 | 190 | 117.0 | 3.0 |
| 20 | 390 | 100 | 190 | 115.0 | 2.9 |
| | | | Average | | 2.7 |
| | | | Minimum | | 2.1 |
| | | | Std. dev. | | 0.4 |
| | | | Characteristic strength | | 2.04 |

Table A2-68: Density test results of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:6:4 mix proportion (BC 6)

| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Density kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12498 | 11490 | 12680 | 5800 | 1670 |
| 2 | 12440 | 11446 | 12690 | 5900 | 1686 |
| 3 | 12498 | 11496 | 12736 | 5896 | 1681 |
| 4 | 12456 | 11458 | 12680 | 5880 | 1685 |
| | | | Average | | 1680 |
| | | | Standard deviation | | 7.2 |

Table A2-69: Water absorption of solid blocks made with Cement: Bottom Ash: Crushed rock aggregate= 1:6:4 mix proportion (BC 6)



| Ser. No | Normal Weight (g) | Oven Dry Weight (g) | Wet Weight (g) | Weight in water (g) | Water absorption kg/m$^3$ |
|---|---|---|---|---|---|
| 1 | 12498 | 11490 | 12680 | 5800 | 173 |
| 2 | 12440 | 11446 | 12690 | 5900 | 183 |
| 3 | 12498 | 11496 | 12736 | 5896 | 181 |
| 4 | 12456 | 11458 | 12680 | 5880 | 180 |
| | | | Average | | 179 |
| | | | Standard deviation | | 4.5 |

Comment: This mix is recommended as a proper mix to use in production, since it satisfies the requirement specified in SLS 855 for compressive strength and water absorption.
Density is relatively low when compared with mix with traditional fine aggregates.

**Annexure 3: Details of cost analysis**

In the laboratory trial, to produce 20 blocks, 220 liters of total solid material was used.

Loose bulk densities of all raw materials were determined using the measuring boxes or cylinders.

**QBC 1**

1 cement: 2 quarry dust: 2 bottom ash: 3 crushed rock aggregate

To produce 1 block, the following quantities are required.

| | | |
|---|---|---|
| Cement | = 220/20 x 1/8 | = 1.375 l |
| Quarry dust | = 220/20 x 2/8 | = 2.75 l |
| Bottom Ash | = 220/20 x 2/8 | = 2.75 l |
| Crushed rock aggregate | = 220/20 x 3/8 | = 4.125 l |



Therefore, to produce 1000 blocks, materials requirement is as follows:

| | |
|---|---|
| Cement | = 220/20 x 1/8 x 1000 = 1,375 l=1,650kg=33 bags |
| Quarry dust | = 220/20 x 2/8x1000= 2,750 l= 97ft$^3$≈ 1cube |
| Bottom Ash | = 220/20 x 2/8x1000= 2,750 l= 97ft$^3$≈ 1cube |
| Crushed rock aggregate | = 220/20 x 3/8x1000= 4,125 l= 146ft$^3$≈ 1.5cube |

Material cost to produce 1000 Nos of QBC 1 mix is analysed in Table A3-1.

Table A3-1: Material cost to produce 1000blocks of QBC 1

| Material | Quantity | Unit Cost(Rs) | Transport Cost (Rs) | Total Cost (Rs) |
|---|---|---|---|---|
| Cement | 33bags | 880.00/bag | 1,000.00 | 30,040.00 |
| Quarry dust | 1cube | 7,600.00/cube | 1,000.00 | 8,600.00 |
| Bottom Ash | 1cube | - | 2,000.00* | 2,000.00 |
| Crushed rock aggregate (5-10mm) | 1.5cube | 7,600.00/cube | 1,000.00 | 12,400.00 |
| | | | | 53,040.00 |

Material cost per block = Rs. 53.04

* Assumed production plant is within 20km distance from the power plant

<u>Production cost in medium scale</u>

Electricity, labor, water and other overheads=Rs.5,000.00

Considering production rate is 2,000 blocks per day

Total Cost=Rs.(2000 x 53.04 + 5,000) = Rs. 111,080.00



Then, cost per block= Rs.55.54

Add Rs.5/= per block as profit**, cost per block is Rs. 60.54

** As per the questionnaire survey medium scale block producers expect a profit of Rs.5/= per block

Normal cost in the market Rs. 55 to 75 per block

**BC 1**

1 cement: 4 bottom ash: 3 crushed rock aggregate

To produce 1 block, the following quantities are required.

| | | |
|---|---|---|
| Cement | = 220/20 x 1/8 | = 1.375 l |
| Bottom Ash | = 220/20 x 4/8 | = 5.5 l |
| Crushed rock aggregate | = 220/20 x 3/8 | = 4.125 l |

Therefore, to produce 1000 blocks, materials requirement is as follows:

| | |
|---|---|
| Cement | = 220/20 x 1/8 x 1000 = 1,375 l=1,650kg=33 bags |
| Bottom Ash | = 220/20 x 4/8x1000= 5,500 l= 194ft$^3$≈ 2cube |
| Crushed rock aggregate | = 220/20 x 3/8x1000= 4,125 l= 146ft$^3$≈ 1.5cube |



Material cost to produce 1000 Nos of BC 1 mix is analysed in Table A3-2.

Table A3-2: Material cost to produce 1000blocks of BC 1

| Material | Quantity | Unit Cost(Rs) | Transport Cost (Rs) | Total Cost (Rs) |
|---|---|---|---|---|
| Cement | 33bags | 880.00/bag | 1,000.00 | 30,040.00 |
| Bottom Ash | 2cube | - | 2,000.00* | 2,000.00 |
| Crushed rock aggregate (5-10mm) | 1.5cube | 7,600.00/cube | 1,000.00 | 12,400.00 |
| | | | | 44,440.00 |

Material cost per block = Rs. 44.44

* Assumed production plant is within 20km distance from the power plant

<u>Production cost in medium scale</u>

Electricity, labor, water and other overheads=Rs.5,000.00

Considering production rate is 2,000 blocks per day

Total Cost=Rs.(2000 x 44.44 + 5,000) = Rs. 93,880.00

Then, cost per block= Rs.46.94

Add Rs.5/= per block as profit**, cost per block is Rs. 51.94

** As per the questionnaire survey medium scale block producers expect a profit of Rs.5/= per block

Normal cost in the market Rs. 55 to 75 per block

**QBC 2**

1 cement: 1 quarry dust: 3 bottom ash: 1.5 crushed rock aggregate

To produce 1 block, the following quantities are required.

| | | |
|---|---|---|
| Cement | = 220/20 x 1/6.5 | = 1.7 l |
| Quarry dust | = 220/20 x 1/6.5 | = 1.7 l |
| Bottom Ash | = 220/20 x 3/6.5 | = 5.1 l |
| Crushed rock aggregate | = 220/20 x 1.5/6.5 | = 2.54 l |

Therefore, to produce 1000 blocks, materials requirement is as follows:

| | | |
|---|---|---|
| Cement | = 220/20 x 1/6.5x 1000 | = 1,693 l=2032kg=41 bags |
| Quarry dust | = 220/20 x 1/6.5x 1000 | = 1,693 l= 60ft$^3$= 0.6cube |
| Bottom Ash | = 220/20 x 3/6.5x1000 | = 5,077 l= 179ft$^3$= 1.8cube |
| Crushed rock aggregate | = 220/20 x 1.5/6.5x1000 | = 2,538 l= 89.6ft$^3$= 0.9cube |



Material cost to produce 1000 Nos of QBC 1 mix is analysed in Table A3-3.

Table A3-3: Material cost to produce 1000blocks of QBC 1

| Material | Quantity | Unit Cost(Rs) | Transport Cost (Rs) | Total Cost (Rs) |
|---|---|---|---|---|
| Cement | 41bags | 880.00/bag | 1,000.00 | 37,080.00 |
| Quarry dust | 0.6cube | 7,600.00/cube | 1,000.00 | 5,560.00 |
| Bottom Ash | 1.8cube | - | 2,000.00* | 2,000.00 |
| Crushed rock aggregate (5-10mm) | 0.9cube | 7,600.00/cube | 1,000.00 | 7,840.00 |
| | | | | 52,480.00 |

Material cost per block = Rs. 52.48

* Assumed production plant is within 20km distance from the power plant

<u>Production cost in medium scale</u>

Electricity, labor, water and other overheads=Rs.5,000.00



Considering production rate is 2,000 blocks per day

Total Cost=Rs.(2000 x 52.48 + 5,000) = Rs. 109,960.00

Then, cost per block= Rs.54.98

Add Rs.5/= per block as profit**, cost per block is Rs. 58.98

** As per the questionnaire survey medium scale block producers expect a profit of Rs.5/= per block

Normal cost in the market Rs. 55 to 75 per block

**QBC 3**

1 cement: 2 quarry dust: 3.5 bottom ash: 1 crushed rock aggregate

To produce 1 block, the following quantities are required.

Cement = 220/20 x 1/7.5 = 1.5 l

Quarry dust = 220/20 x 2/7.5 = 3 l

Bottom Ash = 220/20 x 3.5/7.5 = 5.2 l

Crushed rock aggregate = 220/20 x 1/7.5 = 1.5 l

Therefore, to produce 1000 blocks, materials requirement is as follows:

Cement = 220/20 x 1/7.5x 1000 = 1,467 l=1760kg=36 bags

Quarry dust = 220/20 x 1/7.5x 1000 = 1,467 l= 52ft$^3$= 0.52cube

Bottom Ash = 220/20 x 3.5/7.5x1000 = 5,133 l= 181ft$^3$= 1.9cube



Crushed rock aggregate = 220/20 x 1/7.5x1000= 1,467 l= 52ft$^3$= 0.52cube

Material cost to produce 1000 Nos of QBC 1 mix is analysed in Table A3-4.

Table A3-4: Material cost to produce 1000blocks of QBC 1

| Material | Quantity | Unit Cost(Rs) | Transport Cost (Rs) | Total Cost (Rs) |
|---|---|---|---|---|
| Cement | 36bags | 880.00/bag | 1,000.00 | 32,680.00 |
| Quarry dust | 0.52cube | 7,600.00/cube | 1,000.00 | 4,952.00 |
| Bottom Ash | 1.9cube | - | 2,000.00* | 2,000.00 |
| Crushed rock aggregate (5-10mm) | 0.52cube | 7,600.00/cube | 1,000.00 | 4,952.00 |
| | | | | 44,584.00 |

Material cost per block = Rs. 44.59

* Assumed production plant is within 20km distance from the power plant

Production cost in medium scale

Electricity, labor, water and other overheads=Rs.5,000.00



Considering production rate is 2,000 blocks per day

Total Cost=Rs.(2000 x 44.59 + 5,000) = Rs. 94,180.00

Then, cost per block= Rs.47.09

Add Rs.5/= per block as profit**, cost per block is Rs.52.09

** As per the questionnaire survey medium scale block producers expect a profit of Rs.5/= per block

Normal cost in the market Rs.55 to 75 per block

**BC 6**

1 cement: 6 bottom ash: 4 crushed rock aggregate

To produce 1 block, the following quantities are required.

| | | |
|---|---|---|
| Cement | = 220/20 x 1/11 | = 1l |
| Bottom Ash | = 220/20 x 6/11 | = 6l |
| Crushed rock aggregate | = 220/20 x 4/11 | = 4l |

Therefore, to produce 1000 blocks, materials requirement is as follows:

| | |
|---|---|
| Cement | = 220/20 x 1/11x 1000= 1,000 l=1,200kg=24 bags |
| Bottom Ash | = 220/20 x 6/11x1000= 6,000 l= 212ft$^3$≈ 2.2cube |
| Crushed rock aggregate | = 220/20 x 4/11x1000= 4,000 l= 142ft$^3$≈ 1.5cube |

Material cost to produce 1000 Nos of BC 1 mix is analysed in Table A3-5.



Table A3-5: Material cost to produce 1000blocks of BC 1

| Material | Quantity | Unit Cost(Rs) | Transport Cost (Rs) | Total Cost (Rs) |
|---|---|---|---|---|
| Cement | 24bags | 880.00/bag | 1,000.00 | 22,120.00 |
| Bottom Ash | 2.2cube | - | 2,000.00* | 2,000.00 |
| Crushed rock aggregate (5-10mm) | 1.5cube | 7,600.00/cube | 1,000.00 | 12,400.00 |
| | | | | 36,520.00 |

Material cost per block = Rs. 36.52

* Assumed production plant is within 20km distance from the power plant

Production cost in medium scale

Electricity, labor, water and other overheads=Rs.5,000.00

Considering production rate is 2,000 blocks per day

Total Cost=Rs.(2000 x 36.52 + 5,000) = Rs.78,040.00

Then, cost per block= Rs.39.02

Add Rs.5/= per block as profit**, cost per block is Rs.44.02

** As per the questionnaire survey medium scale block producers expect a profit of Rs.5/= per block

Normal cost in the market Rs.55 to 75 per block

**Large Scale production**

Number of blocks shall be produced per day (single and double sizes)



Table A3-6: Cost on Basis- Output of 25MT Bottom Ash from plant per day

| Mix | Requirement of coal ash to produce I block | | No. of blocks from 25 tons of bottom ash |
|---|---|---|---|
| | Bulk volume (l) | Weight (kg) | |
| QBC 1 | 2.75 | 2.1 | 11905 |
| BC 1 | 5.5 | 4.125 | 6060 |
| QBC 2 | 5.1 | 3.825 | 6535 |
| QBC 3 | 5.2 | 3.9 | 6410 |
| BC 6 | 6 | 4.5 | 5555 |