STRENGTH PARAMETERS OF COMPRESSED STABILIZED EARTH BLOCKS USING FURNACE BOTTOM ASH AS A CEMENT REPLACEMENT

Kasuni Liyanage,
Final year undergraduate (Department of Civil Engineering, University of Moratuwa)
(email: kasuniliyan@gmail.com)
Amali Jayathilake,
Final year undergraduate (Department of Civil Engineering, University of Moratuwa)
(email: amalidjcr@gmail.com)
Thilini Kumari,
Final year undergraduate (Department of Civil Engineering, University of Moratuwa)
(email: mdthiliniwasanakumari@gmail.com)
Chintha Jayasinghe,
Professor (Department of Civil Engineering, University of Moratuwa)
(email: chintha@civil.mrt.ac.lk)
S.M.A. Nanayakkara,
Professor (Department of Civil Engineering, University of Moratuwa)
(email: sman@civil.mrt.ac.lk)

Abstract

Furnace Bottom Ash (FBA) is the waste by product that falls to the bottom of the pulverized coal furnaces when the ash particles become too large to be carried in the flue gases. Physical appearance of FBA is porous in nature, grey in colour and fine sand to coarse gravel range of particle size. FBA has similar chemical properties to Pulverized Fuel Ash (PFA) with the three predominant elements being silica, aluminum and iron, the oxides including considerable pozzolanic properties. Current applications of this by product include aggregate in lightweight concrete products, filler material for structural applications and embankments, Aggregate in road bases, sub-bases, and pavement and feed stock in the production of cement.

In this research, FBA obtained from Norochchole power plant in Sri Lanka is used as a cement replacement in investigating dry and wet compressive strengths of Compressed Stabilized Earth Blocks with 30% and 50% replacement of cement. The CSE blocks used in the experimental programme were manufactured using a mix of laterite soil and cement (6% of cement). A Comparison and a relationship of unit strength Vs wall panel strength is obtained in order to recommend practical applications of the final product.

Keywords: Furnace bottom ash (FBA), Compressed Stabilized Earth Blocks (CSEB), Building material, Cement replacement, Compressive strength

1. Introduction

Furnace bottom ash is generated as a waste by product of burning coal in coal fired power plants. Coal is a fossil fuel which has the highest availability as a global natural resource and it is anticipated to have available for another 120 years which is more than the availability of oil and gas. According to World Coal Association (WCA) statistics, coal provides 30.3% of global primary needs and satisfies 42% of the world's electricity demand. It also shows that the total world coal production is about 7.7 billion tonnes in 2011 and has an annual growth rate of production of about 4.4%. Surveys done by American Coal Ash Association (ACAA) show that total production of Coal Combustion Products (CCP) is about 130 million tonnes in 2012 in which about 13% is Bottom Ash. Out of the 17.8 million tonnes of Bottom ash produced only 42% is being utilized. The rest of this valuable waste product is disposed to the environment through ash ponds.

Disposal of Bottom ash can create massive environmental pollution such as ground pollution, ground water pollution etc. Therefore there is a rising need to occupy this coal power plant by product, FBA in any useful application other than dumping it to the environment. Utilization of FBA in building materials will create immense benefits to the construction industry. Sustainability of the final product is the key advantage in this application since the today's world is heading to Green and Sustainable future in construction industry. Also the cost of the final product is low compared to other alternatives. Therefore it can be clearly seen that the need to investigate the useful applications of FBA in building materials is significantly important.

During the past decade few research works has been done using bottom ash in manufacturing construction materials. The main reason to incorporate Bottom ash in building materials is that it shows some pozzolanic properties similar to fly ash. Cheriafa et al (1999) state that at early ages bottom ash does not react with calcium hydroxide. Pozzolanic reaction of bottom ash proceeds slowly until 14 days and accelerates gradually after 28 days to 90 days. They have recommended allowing the use of bottom ash in concrete after finding that the strength activity indexes with Portland cement determined on standard mortars according to the European standard ENV450 have reached 0.88 at 28 days and 0.97 at 90 days. Also they have stated that adequate grinding can also improve the pozzolanic activity of bottom ash after finding that 28-day strength index of ash has increased by 27% when it is ground for 6 h in laboratory ball mill [7].

Most common application is to utilize FBA as an aggregate in producing concrete. Bai Y. et al (2005) have investigated a concrete with the replacement of sand by furnace Bottom Ash (FBA) at different percentages by mass (0%, 30%, 50%, 70%, and 100%). When the replacement of sand by furnace Bottom Ash increases, compressive strength and drying shrinkage decrease at fixed W/C ratio. When furnace Bottom Ash content increases beyond 30% replacement level, drying shrinkage increases at fixed slump conditions. However they have recommended the best furnace Bottom Ash replacement level as 30% with the help of previous studies. This level provides concrete which has compressive strength range from 40 to 60N/mm² with some sort of beneficially value of drying shrinkage [9]. Special types of concrete such as Fibre-Reinforced Cellular Concrete (FRCC) could also be manufactured with the use of bottom ash as an aggregate. The light weight concrete produced with bottom ash (density less than 2000 kg/m3) with high strength ranging from 47 to 49 MPa. However addition of steel fibres to the concrete with bottom ash can cause to increase self weight but to improve the compressive strength meanwhile preventing the sudden failure of concrete [4]. FBA has also been utilized as a replacement of cement in concrete production. When FBA was replaced by 10% of cement, the 56 day compressive strength has increased approximately 5%, compared to the standard mixture. But it has led to a decrease in the strength when ash addition higher than this amount. Compared to the common practice of fly ash usage, this is relatively lower substitution ratio because of the different phase distributions and higher unburned carbon contents of bottom ash [5].

Since Bottom ash is lightweight in its physical nature, it is also popular in incorporating in lightweight building materials. FBA is used as Portland cement replacement to produce lightweight concrete (LWC) by autoclave aerated concrete method in Thailand in 2011 by Wongkeo et al [8]. Bottom Ash (BA) was used as a replacement of Portland cement at 10%, 20% and 30% by weight and Aluminium powder was added at 0.2% by weight of solids. It was found that the compressive strength increased with increase in BA replacement of Portland cement especially at 20% and 30% where compressive strengths of more than 10MPa (BA2=10.9MPa and BA3=11.6MPa) were found. The reason for this was caused by tobermorite formation. It is also stated that tobermorite was formed at high temperature (above 100^0C). FBA helps to increase Silica content and thus low Ca/Si ratio can be obtained. It would finally promote tobermorite formation. Tobermorite phase has a larger volume of structure than α-C_2SH phase which causes a decrease in porosity and increase in compressive strength when compared to LWC without BA. Finally they have recommended using up to 30% of BA in cement replacement when producing autoclaved aerated concrete [8].

Furnace bottom ash could also be used to manufacture cementless pressed blocks with fly ash. Literature shows that blocks with fly ash and bottom ash produces higher compressive strength than blocks with only fly ash. Wet compressive strength of specimens was in the range of 52–60% times of dry compressive strength. However Sodium Silicate (Na_2SiO_3) was used as an alkali activator in order to form Geopolymer [3]. Compressed earth bricks using stockpiled circulating fluidized bed combustion ashes (SCFBCA) which contains fly ash, bottom ash and gypsum, were investigated in 2009. The brick was manufactured in a similar method as in conventional earth bricks. SCFBCA was used as the major raw material as soil in conventional earth bricks. The results of the compressive strength of all the specimens were within the range of 12.1MPa to 40.6MPa. However it was found that the use of lime with fly ash instead of cement has considerable increase in compressive strength. Also lime has effects on achieving higher early strength [2].

2. Objectives and Methodology

The main objectives of this research can be listed as below:

- Development of a sustainable building material termed as Compressed Earth Bottom Ash block (CEBA), a Compressed Stabilized Earth Block (CSEB) using Furnace Bottom Ash (FBA) as a raw material which is generated as a byproduct of Norochchole Power plant and currently considered as a solid waste.

- Investigation of mixing, casting, and curing methods in order to optimize the final product economically as well as environmental friendly manner.

- Determination of compressive strength and other strength parameters of the block and the wall panel.

- Analysis of the final results in order to find applicability of the new product.

The following methodology is adopted in achieving the main objectives of this research.

- With a detailed experimental programme, the optimum mix proportions in production and the strength parameters were determined in the CEBA block.

- Comparison of compressive strength of a unit CEBA block and block masonry with similar conventional materials was carried out.

- Cost effectiveness of the CEBA block was determined in order to justify the applicability.

3. Compressed Earth Bottom Ash Block (CEBA)

Compressed Stabilized Earth Blocks (CSEB) consist soil with a stabilizing agent compressed by different types of manual or motor-driven press machines. Generally they are stabilized with cement or lime. CSEB are used as an alternative building material for burnt clay bricks and Cement Sand Blocks. This is an eco friendly and cost-effective wall construction material as most of the generally available sandy soil and gravel soil can be used for manufacturing of CSEB. Soil can easily be extracted and used for production of these blocks. Soil is mixed in certain proportions of cement, usually 5-10% when producing CSEB. Unlike normal clay bricks, burning is not necessary. There is no sand required for CSE block production. Hence, low energy consumption and low environmental pollution or degradation occurs with the production of these blocks.

A constant pressure press is used to manufacture blocks. It can be done either manually or mechanically. In manual method, man force is applied on a lever arm by one or two people until it reaches the maximum pressure. One problem with this type of machine is that it can produce blocks of different thicknesses depending on how much material is filled into it. It is very important with this type of machine to have a gauge box so that the same amount of mix can be kept constant almost in every block. Therefore all the blocks can have the same thickness.

The stabilization can be achieved by means of physical, mechanical and chemical. Physical stabilization is expected to limit the fines content of soil to about 20-30% of soil. Mechanical stabilization is expected to increase the density by compaction of the earth at a compaction ratio of about 1.65 to 1.85 with suitable moisture condition. Chemical stabilization is carried out with the use of bonding agent that can react with earth to retain its strength under the saturated conditions. Generally cement is used to stabilize soil at 5% to 6% ratio [6]. Humid curing is done for 7 days after casting the block and they are kept for another 21 days in a stack fully covered with a plastic sheet. In this experiment Bottom ash is used as a bonding agent with the concept of cement replacement. CSEB are cast using two mixes replacing cement by 33% and 50% from FBA.

4. Experiment

Experimental programme was conducted in accordance with Sri Lanka Standard 1382 Part 1:2009. Some alterations were adopted in the programme in order to achieve possible practical conditions. The blocks were manufactured in a block manufacturing plant. The interlocking hollow blocks were used in the experiment and the dimensions of the block are 300mm of length × 150mm of width × 100mm of height. It can be classified as Type 3 blocks according to Sri Lanka Standard 1382 Part 1:2009. Also the maximum dimensional tolerance of ±5mm was successfully achieved in the experiment.

4.1 Materials

The materials used for the block are soil, cement, bottom ash and water. Jar test performance confirmed the good lateritic properties of the soil used in the experiment. Soil was prepared by screening and grinding in order to remove macro organic matter and oversize gravel particles and to break lumps of dry clay. Ordinary Portland cement was used with Norochchole furnace bottom ash as the stabilizer in the block. The physical appearance of FBA can be declared as a grey lightweight aggregate as shown in Figure 1. The transported bottom ash from Norochchole power plant consist small amount of moisture since the bottom ash from the plant was disposed through a water sprinkler in order to minimize dust distribution. Sieve analysis of FBA was performed in order to find physical suitability as a stabilizer.

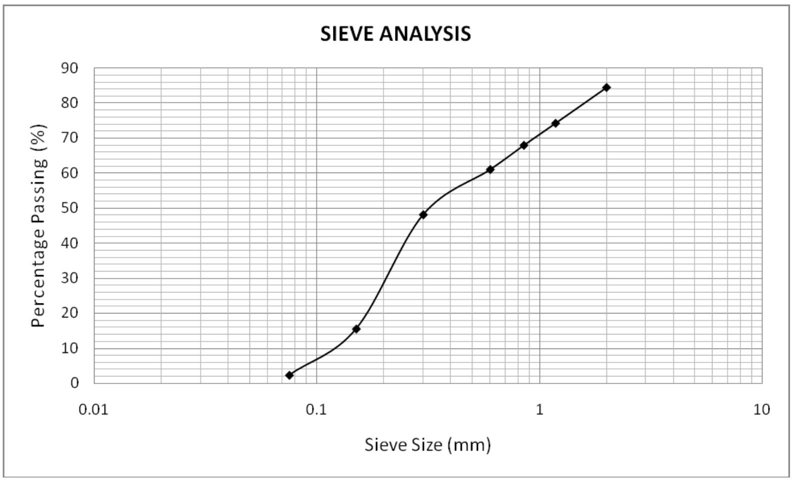

Figure 1Sieve analysis of furnace bottom ash

4.2 Mixing, compacting and curing

Ground soil was mixed with cement and bottom ash according to mix design in a volume batched method using a gauge box. The ingredients were thoroughly mixed together by the Mixer for about three minutes before adding water. Water content was determined by performing drop test. Mixing was carried out for another three minutes after adding water. Blocks were pressed by hydraulic compacting machine. The compaction ratio of the blocks was kept above 1.65 in order to achieve proper compaction. The machine operator had to adjust the compaction ratio for each block since the moisture content of each block varied due to the existed variation in the soil moisture content. The freshly casted blocks were then removed from the mould and stacked for curing. Water sprinkling method was used as curing in the blocks for 7 days and the blocks were covered by a polythene sheet during the curing period.

4.3 Construction of CSE masonry

CSE masonry wall construction was carried out after 7 day curing period of the freshly cast blocks. Stretcher bond was used to construct walls using CSE interlocking blocks. Cement soil grout was used as a binder in laying these interlocking blocks. Soil was sieved by a 2.36 mm mesh and soaked in water for 24 hours. Two parts of saturated soil was mixed with one part of cement by adding adequate amount of water to make a paste. Prepared paste was applied on blocks using a sponge. After soaking blocks in a water bath, they were placed in a way maintaining proper verticality and perfect horizontal groves created by chamfers. The thickness of the wall was equal to the width of the block i.e. 150 mm. To ensure continuity in the vertical direction voids of wall were filled with a mix of 1:3:6 cement, sand and soil.

4.4 Testing

The blocks were tested for dry compressive strength, wet compressive strength, water absorption and dry density. The mix design is shown in Table 1. 6 Nos of specimens from each mix were used to find dry and wet compressive strength and 2 Nos of specimen from each mix were used to find moisture absorption.

Table 1Mix design of CEBA blocks

Mix No	*Soil (%)*	*Cement (%)*	*FBA (%)*	*Cement replacement (%)*
1	*94*	*4*	*2*	*33*
2	*94*	*3*	*3*	*50*

Dry and wet compressive strength tests were carried out after 28 days of casting for both mixes.All specimens used for testing dry and wet compressive strength were capped with 1:3 cement sand mortar using plywood sheet at top and bottom to a thickness of 7mm. Prepared specimens were kept in an oven for 24 hours. After this period three of them were left under ambient temperature for another 24 hours before testing dry compressive strength and remaining three specimens were kept under saturated surface dry condition before testing wet compressive strength. To obtain saturated surface dry conditions, specimens were immersed in water for 24 hours.

Water absorption test was carried out after 28 days of casting the blocks for each mix. Two specimens from each mix were immersed in clean water at ambient temperature for 24 hours. After this period specimens were removed from water, allow them to drain for not more than 1 minute and excess surface water was removed with a damp cloth. The saturated surface dry masses of specimens were weighed immediately to the nearest 1g. Each specimen was placed in the drying oven at 105^{o}C for 48 hours until constant mass is achieved. After this period specimens were taken out from oven and allow them to cool down to room temperature. Then specimens were weighed again to the nearest 1g. Water absorption of each specimen was determined according to the Sri Lanka Standards for CSE Blocks.

The wall panels were tested for 28 day compressive strength. 2 Nos of wall panels for each mix were tested and average compressive strength was obtained. All wall panels were capped with 1:3 cement sand mortar to a thickness of 7mm on the same day of block casting. The panels were tested in the Universal compression testing machine by using two I beams at the edges of the panels in order to distribute the compression load uniformly. The load was applied in a rate of 2.5 tonnes per min and the strain for every 0.2 tonnes was measured using dial gauges at the two edges of the panel as shown in figure 2.

Figure 2Testing of wall panel

5. Results and Analysis

Compressive strength of a unit and water absorption from each mix of the CSE blocks can be summarized as shown in Table 2.

Table 2Results of strength parameters of CEBA blocks

Mix No	*Average Block Dry Compressive Strength (N/mm^2)*	*Average Block Wet Compressive Strength (N/mm2)*	*Wet/dry strength ratio*	*Average Wall Panel Compressive Strength (N/mm^2)*	*Water absorption (%)*
1	*3.108*	*1.640*	*0.53*	*-*	*19.15*
2	*3.507*	*1.749*	*0.50*	*1.511*	*17.35*

The results show that wet to dry strength ratio for the CSE block using bottom ash is about 0.51 which is above the allowable minimum value of 0.4. The dry compressive strength has increased from 3.1 N/mm^2 to 3.5 N/mm^2 with 33% and 50% FBA replacement of cement respectively. Also the wet compressive strength has increased from 1.64 N/mm2 to 1.75 N/mm2 with 33% and 50% FBA replacement of cement respectively. It is interesting to find out both the dry compressive strength has increased with the increase of cement replacement by bottom ash (Figure 2). Furthermore the water absorption ratio has decreased from 19.15% to 17.35% with the increase of cement replacement by bottom ash.

Since bottom ash has a particle size distribution range from 60 µm to 2 mm, it can be considered as a well graded material with respect to cement which has a uniform particle size of about 45 µm. Well graded material can be compacted in a higher compaction ratio than a poorly graded material, thus achieving a higher density. Furthermore the lightweight property of bottom ash makes it easy to mix throughout the mixture homogeneously, where as cement particles tend to fall in to the bottom of the mixer and flocculate at the bottom thus reducing the efficiency. Due to the above reasons the blocks with higher bottom ash percentage achieves higher strength.

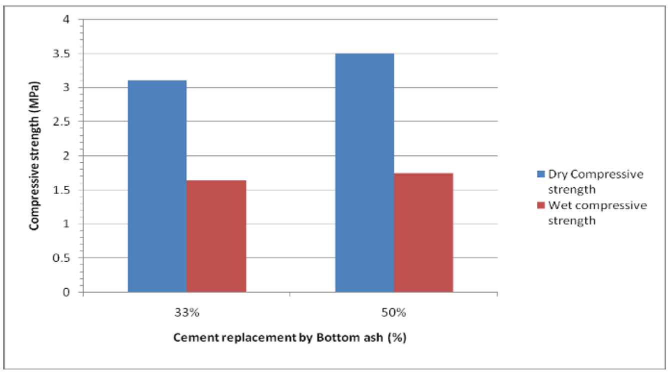

Figure 3Compressive strength Vs cement replacement by bottom ash

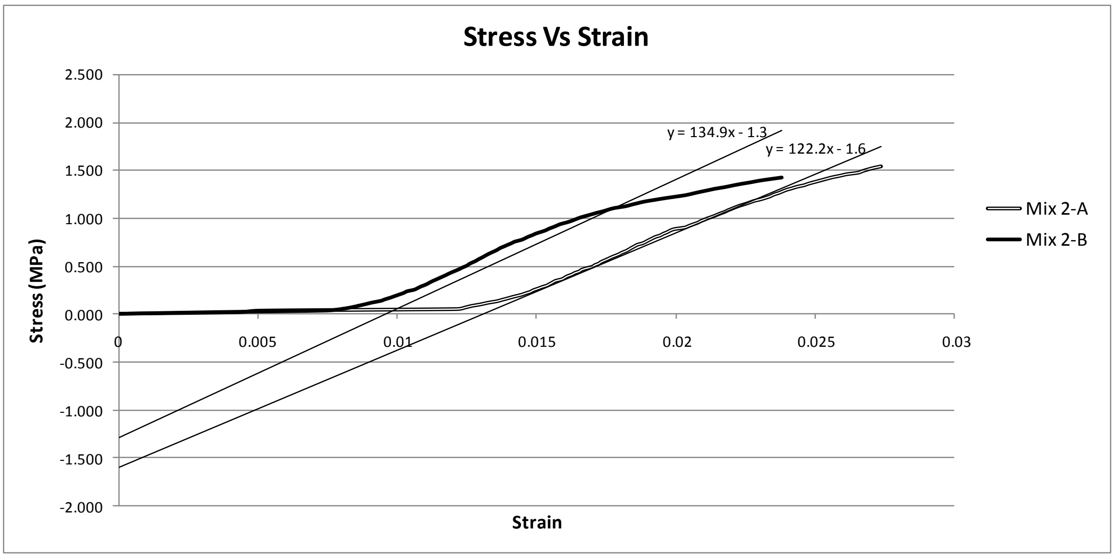

Figure 4 Stress Vs strain of wall panels

Using figure 4, Elastic modulus (E value) of the CEBA wall panel can be calculated as 130MPa. Hence the stiffness of the wall panel is very poor.

6. Conclusion

CEBA block can be considered as a sustainable solution for the building and construction industry due to various reasons. Use of locally available materials, less energy consumption and minimum pollution prove the sustainability of the CEBA block. Also sustainability of the coal power plants is improved since the bottom ash waste product is properly reused in an environmentally friendly manner. On the basis of the test results, it was clear that both the dry and wet compressive strengths have increased with the increase of bottom ash used as a cement replacement. The highest compressive strength of 3.5 N/mm^2 the CEBA block and the highest wall panel strength of 1.5 N/mm^2 was achieved with 50% cement replacement by bottom ash. Thus it can be concluded that CEBA block has adequate dry and wet compressive strength to be used in single storey and two storey load bearing construction. Finally it can be recommended to use furnace bottom ash as a cement replacement up to 50% in the CEBA block. Further it is suggested to do more research on CEBA blocks based on varying the standard stabilizer content of CSE blocks.

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