Development of Coal Ash – GGBS based geopolymer bricks

Bennet Jose Mathew[1], Sudhakar M [2], Dr. C Natarajan [3]

PG student[1] / Research Scholar[2] / Professor of Civil Engg[3]
National Institute of Technology,
Trichy. 620015 India
Email: sudhakar5566@gmail.com

Abstract
Study has been carried out on development of geopolymer binder based bricks using fly ash, GGBS and bottom ash. A mixture of sodium silicate and sodium hydroxide were used to prepare the bricks which were cured at ambient temperature. The effect of percentage of binder by weight, percentage of GGBS by weight in total aluminosilicate binder materials, sodium silicate to sodium hydroxide ratio and alkaline liquid to aluminosilicate solid ratio were studied using full factorial design. Percentage of binder and ratio of alkaline liquid to alumiosilicate solid ratio had significant impact on the strength of brick. Bricks were casted in industrial site from the best mix obtained from factorial design experiment and mechanical properties like compressive strength and water absorption were noted.

Keywords: Compressive strength, factorial design, Geopolymer, waste create bricks, water absorption

1. INTRODUCTION

The huge demand from housing industry due to population explosion has entailed the need for sustainable building materials especially bricks. Researchers have tried to incorporate fly ash, ground granulated blast furnace slag (GGBS), lime stone dust, rice husk ash, welding flux slag and other waste products into bricks so as to improve its sustainability [1-6]. An interesting area of research which has attracted interest of many scholars is Geopolymer binder which utilizes industrial waste products to form sustainable green binders.
As per TERI (2001) report, India produces more than 1400 billion bricks per year using 350 million tons of top soil by burning 24 million tons of coal thereby emitting 42 million tons of CO_2 .

In India, it is estimated that by end of 2012, from the total thermal capacity of about 90 coal / lignite based Thermal Power plants, generate ash in the form of fly ash (80-90%) and bottom ash (10-20%) would be of the order of 173 Million Tons(Mt) per annum considering 38% ash content in coal as an average and at 80% Plant Load Factor (CEA 2009-10). It is further estimated that only about 51% of the ash generated found gainful utilization. Given the fact that economic growth of the Nation is generally linked to power availability and given the trend of high proportions of coal based thermal power stations (TPS), fly ash generation is likely to increase in future. It is estimated that coal ash generation will likely to grow over 200Mt by the year 2017. Unless we find more ways to utilise this industrial waste fully, in line with its output, it will greatly endanger the environment. Hence exploring the possibility of utilising bottom ash (BA) along with Fly ash is interesting avenue for research.

The term geopolymer was termed by Davidovits in 1988 [7] to represent mineral polymers. Geopolymers are chemically similar to Zeolite but has amorphous microstructure consisting predominantly of Si and Al atoms. During the synthesized process, silicon and aluminium atoms are combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks [8-11].

Most of the literature in geopolymer deals with geopolymer pastes and geopolymer concrete. Geopolymer based binder was patented in USA in 1988 as High Strength Mineral polymer and the binder was prepared using GGBS which replaced cement mortar in precast structural elements. Geopolymer has advantages like availability of abundant raw materials, quick strength gain, good durability especially in acidic environment, reduced energy consumption and reduced greenhouse gas emission [12-15].

Previous study conducted on blocks made of fly ash bottom ash and alkaline solution confirms the feasibility of brick production where in bricks were produced that meet Israelis Standards for blocks [16]. Bricks of strength ranging from 5-60 MPa was also prepared previously using Class F fly ash, sodium silicate and sodium hydroxide solution with forming pressure of 30MPa and cured at elevated temperatures [17]. Research into geopolymer bricks incorporation copper mine tailings, copper mine tailing and cement kiln, fly ash, metakaolin and red mud, red mud and rice husk ash, fly ash and iron making slag and many more have produced promising results [18-22].

Objective of this study is to prepare bricks using bottom ash, fly ash, GGBS, and alkaline solution consisting of sodium hydroxide and sodium silicate. Fly ash and bottom ash are waste products of coal burning power station. The chemical composition of fly ash and bottom ash from same batch will be similar. Bottom ash may consists of particles of size up to 10-15mm.

2. MATERIALS

Fly Ash

The fly ash obtained for the study was from Tuticurin thermal power station, India. Results of XRF analysis of the fly ash is indicated in Table 1. Fly ash falls under Class F as per ASTM Standard [13]. The specific gravity of fly ash was found to be 2.05.

Table 1. Chemical composition of fly ash.

Oxide	Mass Percentage
SiO_2	53.3
Al_2O_3	29.5
Fe_2O_3	10.7
CaO	7.6
SO_3	1.8

GGBS

GGBS is obtained by grinding the quenched blast furnace slag to fine powder. It is important constituent for geopolymer binders cured at ambient temperature . The chemical composition of GGBS of specific gravity 2.18 obtained from local market is given in Table 2.

Table 2 Composition of GGBS as determined by XRF

Oxide	Mass Percentage (%)
SiO_2	35.47
Al_2O_3	19.36
FeO	0.8

CaO	33.25
MgO	8.69
Others	3.25

Bottom Ash

Bottom ash was also procured from Tuticorin Thermal Power Plant, Tamil Nadu. However it was taken from a different batch from that of fly ash and the chemical composition is given in Table 3. Sieve Analysis of bottom ash also was carried out mainly to determine the quantity of particles size distribution and was found to be well graded.

Table 3 Composition of Bottom Ash as determined by XRF

Oxides	**Mass Percentage (%)**
SiO_2	56.76
Al_2O_3	21.34
Fe_2O_3	5.98
CaO	2.88
SO_3	0.72

Sodium Silicate and Sodium Hydroxide

Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) were both procured from local market. Laboratory grade (97% pure) sodium hydroxide was in the form of pellets (3mm approximately) with specific density of 2.13 g/cm^3. The chemical composition of sodium silicate solution was Na_2O=15.23% by mass, SiO_2=35.67% by mass and remaining water. The Molar Ratio (SiO_2/Na_2O) was found to be 2.34. The density of sodium silicate solution was found to be 1.53 g/cm^3.

3. EXPERIMENTAL INVESTIGATION AND RESULTS

A 2^4 full factorial design was adopted for experimental study with each parameter having two levels. Higher and lower levels of the parameters identified for the full factorial design is tabulated in Table 4. The levels were identified based on pilot study conducted by the authors. A total of 16 mixes were derived using full factorial design method and the mixes are listed in Table 5. The Molarity of NaOH solution was kept constant as 6 molar while water to total geopolymer solid (Fly Ash, GGBS, Bottom Ash, NaOH Pellets, and Na_2SiO_3 solute) ratio was kept constant at 0.13.

Table 4 Factors and their levels considered in Factorial design.

Parameter	**Higher Level (+1)**	**Lower Level (-1)**
Percentage Binder by Weight including Aluminosilicate materials and Liquid	40 %	20 %
Percentage of GGBS in Aluminosilicate Binder Material	50 %	10 %
Sodium Silicate to Sodium Hydroxide Ratio	2.5	2
Activator liquid to Aluminosilicate Binder Material Ratio	0.5	0.3

Cubes of 7.07 cm side ($50cm^2$ face area) were casted for each mix. Hand compaction in three layers with 25 blows to each layer was used to compact the mix so as to create the minimum moulding condition that may be used in site. Cubes were cured in ambient temperature for 28 days and were tested for compressive strength. The results of the test along with density are also given in Table 5.

Table 5 Average compressive strength and standard deviation of samples

Mix No	Percentage Binder by Weight	Percentage of GGBS	Na_2SiO_3 to NaOH Ratio	Activator liquid to Alumino-silicate Ratio	Compressive Strength (MPa)	Density (Kg/m^3)	Strength / Density
1	-1	1	-1	-1	0.06	976.204	0.06
2	-1	-1	1	-1	0.08	1025.968	0.08
3	-1	-1	-1	1	0.47	1079.698	0.43
4	-1	1	1	1	0.98	1195.269	0.82
5	-1	-1	-1	-1	0.16	943.9093	0.17
6	-1	1	1	-1	0.11	1038.621	0.11
7	-1	-1	1	1	0.53	1057.129	0.50
8	-1	1	-1	1	0.31	1101.228	0.28
9	1	1	-1	-1	0.64	1150.897	0.56
10	1	-1	1	-1	0.90	1136.251	0.79
11	1	-1	-1	1	3.30	1248.347	2.64
12	1	1	1	1	5.03	1157.224	4.35
13	1	-1	-1	-1	1.02	1141.549	0.90
14	1	1	1	-1	0.45	1094.334	0.41
15	1	-1	1	1	3.70	1215.77	3.04
16	1	1	-1	1	4.07	1273.371	3.19

The best mix in terms of strength and strength to density ratio was found to be Mix 12 and it was used for casting of bricks of dimensions 230mm x 115mm x 75mm. Bricks were moulded using pneumatically operated electric machine with a pressure of value 36 MPa. Bricks were cured at ambient temperature and water absorption and compressive strength at intervals of 7 days, 14 days, 21 days and 28 days were noted as per IS 3496 and the results are given in Figure 1 and Figure 2. The average density of block was found to be 1516.5 kg/m^3.

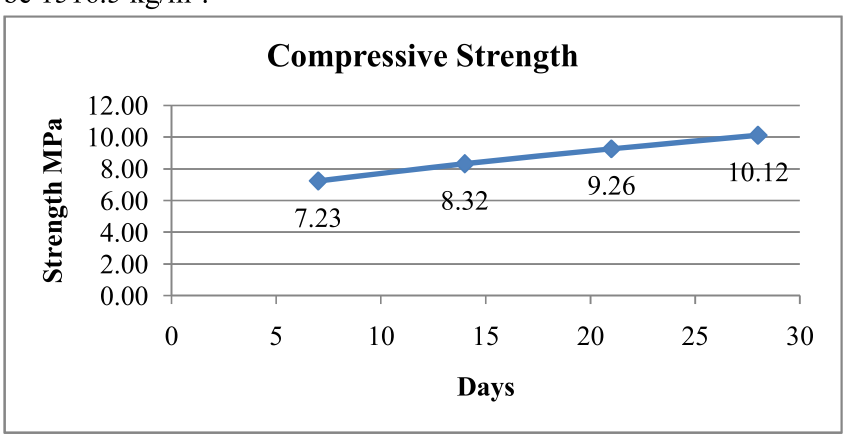

Figure 1. Variation of compressive strength with days

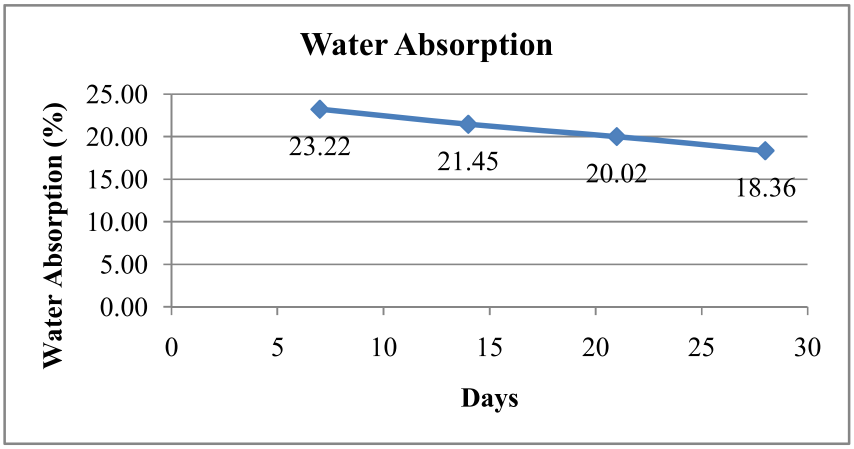

Figure 2. Variation of compressive strength with days

4. DISCUSSION AND CONCLUSION

Most of the mixes under study gave relatively lower strength when compacted by hand compaction method. The parameter which had the highest influence on strength of the mix was binder percentage. When binder percentage by weight level was changed from lower (20%) to higher level (40%) an average change of +2.051 MPa was noted. Changing the Activator liquid to Aluminosilicate Binder Material Ratio from 0.5 to 0.3 also increased the strength considerably (+1.871 MPa). Among the parameter interaction effects binder percentage by weight - Activator liquid to Aluminosilicate Binder Material Ratio had an effect of 1.401 MPa. The average individual effects and average interaction effects of two and more parameters on strength are given in Table 6.

Table 6 Summary of effects and Interaction effects

Parameter / Interaction	Average Effect on Strength (MPa)
Percentage Binder by Weight including Aluminosilicate materials and Liquid (A)	2.051
Percentage of GGBS in Aluminosilicate Binder Material (B)	0.186
Na_2SiO_3 to NaOH Ratio (C)	0.219
Activator liquid to Aluminosilicate Binder Material Ratio (D)	1.871
A- B Interaction	0.131
B – C Interaction	0.155
C – D Interaction	0.306
A – C Interaction	0.044
A – D Interaction	1.401
B – D Interaction	0.434
A – B – C Interaction	-0.031
A – C – D Interaction	0.114
B – C – D Interaction	0.139
A – B- D Interaction	0.321

Among the parameters percentage GGBS had the least effect and among interactions, percentage binder by weight including aluminosilicate materials and liquid - percentage of GGBS in aluminosilicate binder material - Na_2SiO_3 to NaOH ratio had the least effect on strength.

Study conducted on the bricks manufactured using Mix 12 indicates that there is increase in compressive strength of the bricks as curing time goes on. An increase of 15% strength was noted when the curing time was increased from days to 14 days. Reduction in water absorption for the same period was 7.6%. As the strength increases the water absorption reduced. This could be due to filling of pores with binder gel as a result of geopolymerization.

Additionally there was an increase of density of the brick (31%) when pneumatically operated machine was used. This has tremendously increased the compressive strength of the block. But still the density of the block is lower than conventional bricks made using clay.

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