



## **GEOPOLYMER FLY ASH BUILDING BRICK BY ATMOSPHERIC CURING**

**S. D. MUDULI<sup>\*</sup>, B. D. NAYAK and B. K. MISHRA**

Environment & Sustainability Department, CSIR-Institute of Minerals and Materials, Technology,  
BHUBANESWAR – 13 (Orissa) INDIA

### **ABSTRACT**

In the current research work effort has been made to develop geopolymer fly ash building brick under atmospheric curing. Geopolymer building bricks are manufactured by using fly ash and alkaline soda based chemical activator solution in presence of sodium silicate and water by maintaining different  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio. During this work  $230 \times 110 \times 75$  mm size fly ash building bricks are manufactured under atmospheric curing. After 25 days of atmospheric curing the results shows that the geopolymer fly ash building bricks with  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio of 0.038 attain a crushing strength of 8.5 Mpa, which is approximately equal to the strength achieved by hot air curing at  $90^\circ\text{C}$  for 4 hrs.

**Key words:** Geopolymer, Fly ash, Atmospheric curing.

### **INTRODUCTION**

Geopolymerization depends, on the ability of the aluminium ion to induce crystallographic and chemical changes with a silica backbone<sup>1</sup>. Several reports are found in the literature on the synthesis, properties and applications of geopolymers<sup>2</sup>. It is observed that fly ash is one of the possible resource for making geopolymer binders, which is available abundantly<sup>3</sup>. Different potential applications of geopolymer includes manufacture of fire resistant materials, thermal insulation, low-tech building materials, low energy ceramic tiles, refractory items, cements and concretes<sup>4</sup>. Several research works has been carried out on manufacture of geopolymer building bricks by a wide range of hot air curing. Geopolymers produced by using metakaolin have been reported to set at ambient temperature in a short time period<sup>5</sup>. However, curing temperature and curing time have been reported to play important roles in determining the properties of the geopolymer materials made from industrial by-products like fly ash. It is observed that increase in curing temperature resulted into higher compressive strength<sup>6</sup>. It is described that in geopolymerization process fresh mixtures allowed at room temperature for 60 mins,

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<sup>\*</sup> Author for correspondence; E-mail: surabhidipali@gmail.com

followed by curing at 65°C for 90 mins, and then drying at 65°C for complete reaction<sup>7</sup>. It is also observed that long curing time improves the polymerisation process resulting into higher compressive strength but an increase in the curing temperature beyond 60°C did not increase the compressive strength substantially<sup>8</sup> and longer curing time did not decrease the compressive strength of geopolymer product<sup>9</sup>. In this research work, the most important factor is to manufacture fly ash building brick by using geopolymerization process under atmospheric curing.

## EXPERIMENTAL

### Preparation of geopolymerization activator

The process of geopolymerization requires alkaline chemical activator for initiation of reaction in formation of mineral polymer structures. This chemical activator is a synthetically prepared commercial grade sodium hydroxide in pellet form with water and sodium silicate solution in presence of alkaline base chemicals consisting of anions of  $O^{2-}$ ,  $[OH]^-$ ,  $Cl^-$  and  $[SO_4]^{2-}$  in different concentrations<sup>10</sup>. The pH of chemical activator is maintained within 11-12 for suitable geopolymerization reaction.

### Manufacturing process

In the current research work, fly ash; the inorganic solid residue generated from thermal power plant is used as raw material for manufacture of building brick through geopolymerization technology. Alumina and silica are the major chemical constituents of fly ash with minor amounts of other oxides such as Fe, Na, Ca, Mg, and K, etc. The chemical analysis of fly ash has given in Table 1. Fly ash with a suitable weight proportion of alkaline activator is mixed in a pan mixer in presence of the synthetically prepared alkaline activator and water. The manufacturing process of geopolymer fly ash building brick has been designed as: weighing of raw material, preparation of chemical activator, mixing, casting and demoulding followed by curing<sup>11</sup>. The mixtures are used for casting of (230 × 110 × 75 mm) size building brick by applying 20 ton compaction pressure. The cast products are cured under normal atmospheric condition upto 25 days. The crushing strength of the bricks are measured in 5, 10, 15, 20, and 25 days interval. The cast products are also cured under hot air curing at 90°C for 2-10 hrs for a comparison.

**Table 1: Chemical analysis of fly ash**

Constituent %	Na <sub>2</sub> O	MgO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	CaO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>	Cr <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>
Fly ash	0.09	0.285	0.51	0.14	0.47	35.5	59.5	0.94	0.01	2.01

## RESULTS AND DISCUSSION

The principle of geopolymerization has been adopted by making different mix designs of fly ash. The mix design composition of fly ash geopolymer building brick along with the cold crushing strength are presented in the Table 2. The results show that geopolymerization is a temperature dependent reaction. The geopolymer fly ash bricks prepared with  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio 0.025 is showing crushing strength of 6 MPa, in 25 days of atmospheric curing, which does not satisfy the BIS specification of 12894 (2002) where as in 25 days of atmospheric curing fly ash bricks manufactured with  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio 0.038 is showing crushing strength of 8.5 MPa.

**Table 2: Raw material mix design and crushing strength of building brick**

Raw material (wt. %)	Mix-1 (K1)	Mix-2 (K2)	Mix-3 (K3)	Mix-4 (K4)	Mix-5 (K5)
Fly ash	87	87	87	87	87
Activator solution	4	5	6	7	8
Water	9	8	7	6	5
$\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$	0.025	0.038	0.052	0.065	0.078
Days	Crushing strength (Mpa)				
5	2.0	3.0	4.0	6.0	8.0
10	2.5	4.0	6.0	10.0	15.0
15	4.0	6.0	10.0	18.0	28.0
20	5.5	7.0	14.0	31.0	32.0
25	6.0	8.0	18.0	38.0	43.0

The hardening of fly ash mix in presence of alkaline activator generally takes a longer duration to attend the desired strength by atmospheric curing. Therefore, conditions of curing are the major aspects to develop a high quality geopolymer product. The results of the geopolymer fly ash bricks prepared with different  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio cured under hot air curing of  $90^\circ\text{C}$  are presented in Fig. 2b. Results show that in hot air curing also fly ash bricks prepared with  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio 0.25 shows the crushing strength of 6.5 MPa, and 10 MPa with  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio 0.38. From both the Figs. 2 (a) and (b)

it is observed that the strength achieved by hot air curing at 90°C for 4 hrs can be achieved by 25 days of atmospheric curing, which mostly depend upon the alkaline activator solution. The concentration of  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  with respect to alkali ( $\text{Na}_2\text{O}$ ) in the fly ash mix governs the geopolymerization reaction. The anion group chemicals act as the reactant in presence of sodium silicate as a set-modifier. The pH of the chemical activator consisting of sodium and anion group chemicals in water is above 11.0. The concentration of anion group chemicals in the activator is maintained depending on the chemical constitution of the oxides and silicates of aluminum, calcium, magnesium, iron bearing mineral phases, which is needed for effective reaction. The substantial increase in strength of fly ash geopolymer brick is due to the increase of alkali concentration.

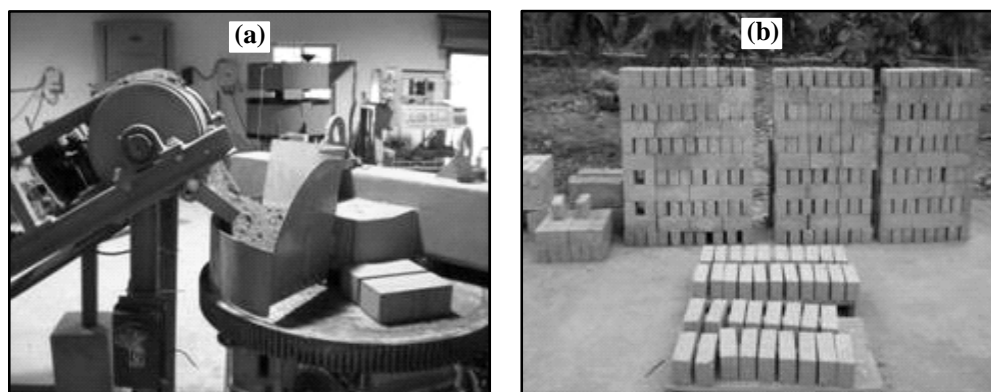


Fig. 1: (a) Casting of fly ash brick, (b) Bricks exposed for atmospheric curing

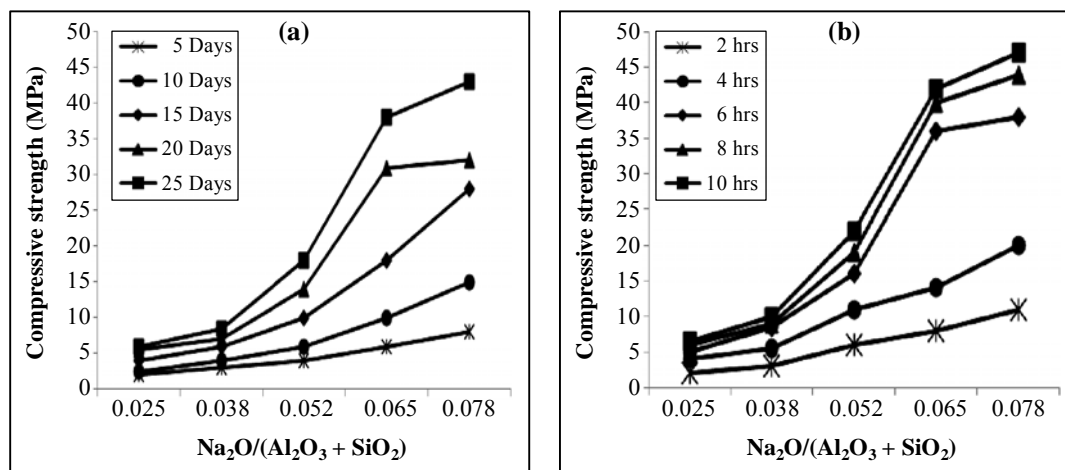
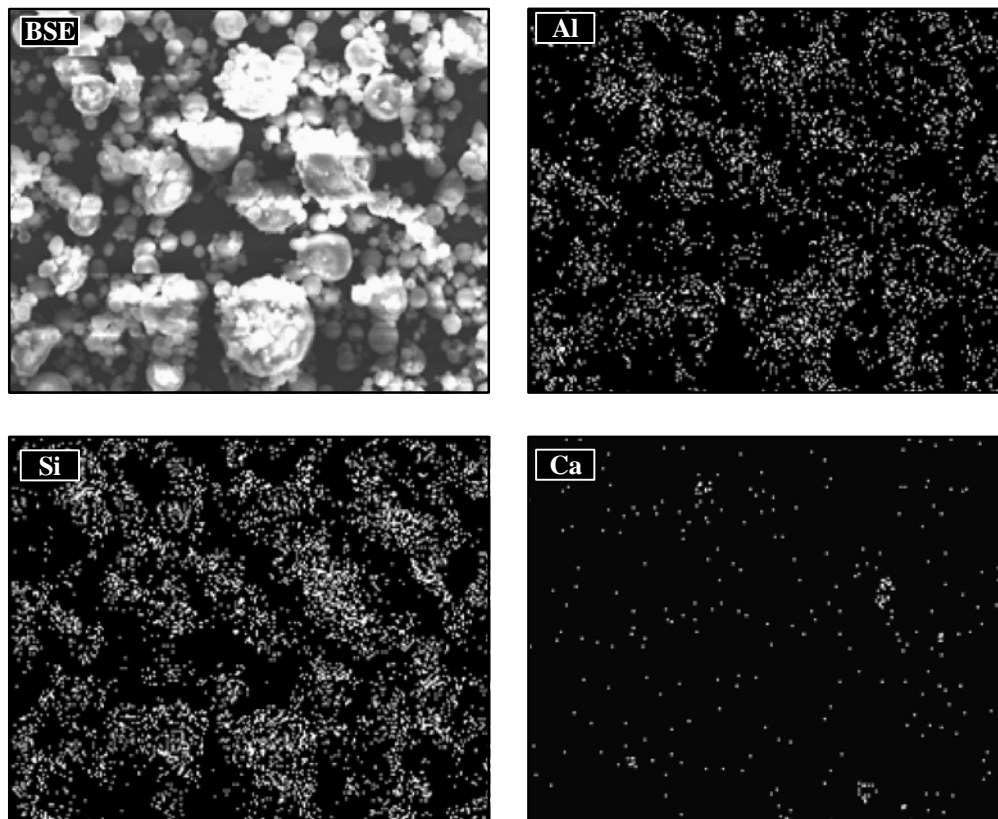
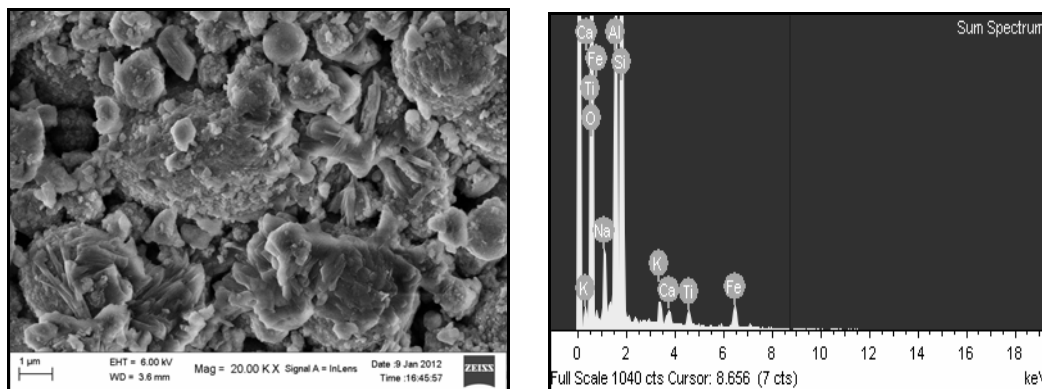


Fig. 2: (a) Bricks under atmospheric curing; (b) Bricks under hot air curing at 90°C

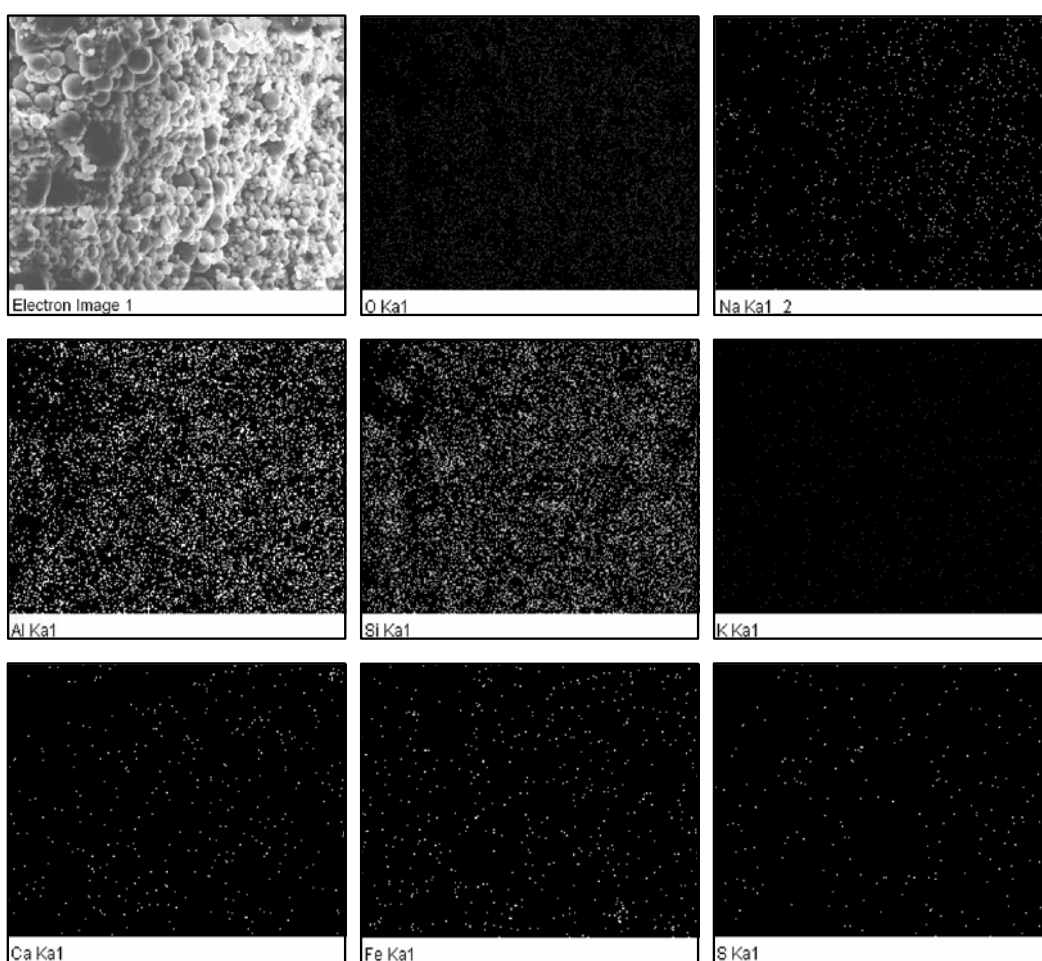
The electron micrograph mapping of fly ash is shown in Fig. 3. It reveals that the fly ash sample mostly consists of Si and Al with traces of Ca, but The electron micrograph of a reacted solidified fly ash product under atmospheric curing having  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3+\text{SiO}_2)$  ratio 0.38 mixture is presented in Fig. 4. The micrograph shows the formation of crystalline structures of sodium assisted cross linked aluminosilicate geopolymer phases. These alkaline phases occur in acicular form and seem to have cross linked into a matrix in the solidified product. The micrograph also shows that the reaction of fly ash in alkaline activator consisting of anions of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  form crystalline grains of sodium aluminum silicates. The elemental distribution of crystalline phases of acicular structure of solidified fly ash product of  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio 0.38 is presented in Fig. 5. The results indicate the presence of Na, Al, and Si, which correspond to form the geopolymer phases with minor to trace amounts of Fe, Ti, S, Mg, Ca, and K. These amorphous to crystalline structures grow in presence of different cation and anion by substitution dissolution and solidification.



**Fig. 3: Mapping of fly ash sample for Al, Si and Ca**



**Fig. 4: SEM of fly ash geopolymer brick with  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio 0.038**



**Fig. 5: Mapping of geopolymer fly ash sample for Al, Si and Ca, Fe, S, K and Na**

The fly ash mix consisting of  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio above 0.038 shows a remarkable increase in the strength under atmospheric curing. The geopolymer fly ash bricks manufactured with  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio 0.078 are cured by exposing to the atmospheric temperature shows a high crushing strength (43 MPa), which mix design may be used for manufacture of concrete. It is observed that with the increase in alkaline activator and  $\text{Na}_2\text{O}/(\text{Al}_2\text{O}_3 + \text{SiO}_2)$  ratio the strength of fly ash product gradually increases. The findings on development of strength indicates that alkaline activator consisting of anions of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  is effective for geopolymer reaction under atmospheric temperature. The  $\text{SO}_4^{2-}$  is an effective ion of higher hydration energy, which promotes hydration of silicates, aluminates and alkalis and enhances the interactions of monomers in formation of crystalline phases<sup>12,13</sup>. The  $\text{Cl}^-$  ion acts as an accilator in gel formation and helps in crystallization<sup>13,14</sup>. In this process, the silica and alumina bearing minerals of fly ash react with the soluble alkalis at ambient temperature to form the geopolymer minerals in presence of anions of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ . Chemical reactions between oxide phases of silica and alumina under alkaline condition form OH bearing sodium-aluminium-silicate structures, which on solidification develops the binding strength<sup>11</sup>.

The dissolution of Al and Si from fly ash occurs in presence of sodium hydroxide, and also the optimum reaction takes place in presence of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  ions in atmospheric temperature to form a compact and strong structure. Inter-coordination of the polymerized minerals helps in the build-up of the cementation property. Depending upon the binding strength the geopolymerisation process is flexible to make high strength building material under atmospheric curing.

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