

Research Article

Reduction of pollution by using Fly ash, bottom ash and granulated blast furnace slag in geopolymer building materials

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Abstract: There are many ways to reduce environmental pollution (carbon dioxide) that causes by production of Portland cement and cause by the increasing of waste material. Geopolymer concrete results from the reaction of a source materials fly ash, bottom ash and granulated blast furnace slag (GBFS) with alkaline liquid. In this experiment fly ash and bottom ash based geopolymer is used as the binder and fillers, in the replacement of Portland cement and natural sand to produce geopolymer concrete. The alkaline liquid that been used in geopolymerisation is the combination of sodium hydroxide (NaOH) and sodium metasilicate (Na₂SiO₂). The result shows that the strength of the geopolymer concrete improved with curing period and temperature.

Keywords: Fly ash, Bottom ash, Granulated blast furnace slag (GBFS), Geopolymer concrete, compressive strength

Introduction:

Portland cement is widely used in concrete industry since many decades ago, however it releases green house gases, i.e. carbon dioxide, into the atmosphere during its manufacture[1]. Geopolymer technology is one of the new technologies attempted to reduce the use of Portland cement in concrete. Fly ash reacts with alkaline solutions to form a cementitious materials; fly ash based geopolymer; which does not emit carbon dioxide into atmosphere. In this work, bottom ash is considered as partial-or full-replacement for sand as fine aggregate in the geopolymer mortar or concrete and fly ash as replacement of Portland cement. To date, Fly Ash & Bottom Ash from Tata Power Plant, (coal used) Jojobera, Jamshedpur, Jharkhand (India) & Granulated Blast furnace slag from Tata Steel Plant Jamshedpur, Jharkhand (India) has not been utilized yet.

Fly ash and bottom ash are residues from the combustion of coal. Fly ash is captured in the chimney while bottom ash is collected from the bottom of the furnace from the coal fired power plant. Furthermore, the particles of fly ash are very fine whereas bottom ash has much larger particle size, which is about the size of sand but more porous. In Tata power plant station, fly ash and bottom ash are disposed off in near pond situated beside the power station.

Fly ash based geopolymer with bottom ash gives emphasis in reducing carbon dioxide emission and in recycling fly ash and bottom ash. Since both are the waste products of coal fired power plant, this

research can lead to the awareness of sustainable development to the society. This is very advisable in sustainable developments to reduce carbon dioxide and to recycle the waste materials. At present time, there is limited information on the influence of parameters on geopolymer available, especially geopolymer with bottom ash as the fine aggregate. As a result, study on the effect of different parameters on the fly ash based geopolymer with bottom ash as sand replacement is needed. In addition, this research can provide additional information and to further introduce geopolymer to concrete industry.

Literature Review

Geopolymers are amorphous to semi-crystalline three-dimensional alumino-silicate polymers similar to zeolites. Geopolymers consist of polymeric silicon-oxygen-aluminium framework with silicon and aluminium tetrahedral alternately linked together in three direction by sharing all the oxygen atoms. The negative charge created by aluminium is balanced by the presence of positive ions such as Na⁺, K⁺, and Ca⁺. The empirical formula of these mineral polymers is Mn[-(SiO₂)_z-AlO₂]_n-wH₂O, where M is an alkali cation such as potassium or sodium, the symbol - indicates the presence of a bond, z is 1, 2 or 3, and n is the degree of polymerization [2]. Geopolymers are environmental friendly materials which do not emit green house gases during polymerisation process. Besides, they need only moderate energy to produce. Geopolymers are made from source materials with silicon (Si) and Aluminium (Al) content, thus they can be made using fly ash, waste-product of coal-fired

power station, as the source materials [3]. Furthermore, geopolymer possesses excellent mechanical properties which does not dissolve in acidic solution and does not generate any hazardous alkali-aggregate reaction even with alkali content as high as 9.2% [4].

Optimum curing temperature of 60 °C was suggested for the study of the geopolymer mortar with small 50 mm cube size. This suggestion is based on the fact that smaller cube is having higher surface area-to-volume ratio compared to larger cube. Which, as a result, the smaller cube is more vulnerable to the high curing temperature and would experience loss of moisture during curing compared with the larger samples[5].

Hardjito et al mentioned that increase in the curing time would also assist the increase in compressive strength which also agreed by other researcher. But, a curing time further than 48 hours does not increase compressive strength significantly [6].

Increase of concentration of NaOH increases the compressive strength of geopolymer. This is mainly because of the concentration of NaOH solution is directly affecting the dissolution of the metakaolinite particulates, which affecting the formation of the geopolymer framework. To have strong inter-molecular bonding strength of the geopolymer, more reactive bond for the monomer is needed. This can be achieved by a better dissolving ability to metakaolinite particulates. To obtain a better dissolving ability to metakaolinite particulates, a higher concentration of NaOH solution is required (Wang, Li, & Yan, 2005). Geopolymer with fluidized bed combustion bottom ash (FBC-BA) experienced a decrease in compressive strength with the increase of the content of FBC-BA in the prepared specimens. Increasing the content of FBC-BA to about 50% caused the decrease of the compressive strength. For the case of normal fly ash concrete incorporating bottom ash as replacement for fly ash, the increase in bottom ash content decreased the compressive strength. Furthermore, most of the compressive strengths were gained after 28 days. The pozzolanic reactivity of bottom ash could be improved with adequate grinding and use it as sand replacement in concrete, where sand is more expensive than bottom ash [7].

Water retainability is defined as the amount of water absorbed into the pores and adsorbed on the rough surface of bottom ash. The usual collapsed-cone test method to determine the saturated surface dry condition was not achievable for bottom ash. Therefore an alternative method based on the gravitational removal of excess water from the bottom ash was introduced to determine the water retainability of bottom ash [8].

Materials and Experimental Details

Source of Materials

Fly ash, bottom ash and granulated blast furnace slag used in this experiment was obtained from Tata power plant, Jojobera and Tata steel plant, Jamshedpur, Jharkhand (India) respectively.

Chemical composition of raw materials:

The chemical composition of the received materials fly ash, bottom ash and GBFS was determined by X-Ray Fluorescence (XRF) analysis is shown in Table 1. According to the chemical composition as shown in Table 1, the mass ratio of SiO₂ to Al₂O₃ in the fly ash, bottom ash and GBFS is 1.97, 2.23 and 2.88 respectively. Mixture of various % composition of Sodium silicate (Na₂SiO₃) solution and various % composition of sodium hydroxide (NaOH) solution were chosen as the alkaline activator. This was because the type of alkaline activator that contained only hydroxides revealed in a lower reaction rate than when soluble silicates were also used as the activators. Sodium-based activator was chosen because it produced a good strength. Particle size analysis of BA is done by the sieve analysis (IS-460-1962*). Granulated Blast furnace slag is 2 hours milled in a ball mill & determined the values of d₁₀, d₅₀ and d₉₀ are 0.52 μm, 8.33 μm and 32.76 μm respectively. Particle size analysis of fly ash & GBFS is done by Laser particle size analyzer (Mastersizer 2000, Malvern, UK) is given in Fig-1 & fineness of bottom ash is shown in table- 2.

Samples preparation:

Fly ash, bottom ash & blast furnace slag (2 hr. ball milled) were mixed in jar at various proportions along with various weight percentage of sodium hydroxide. The different compositions of the mixtures are shown in table 3. Total nine nos. of mix proportions were prepared with varying Si/ Al ratio 2, 2.5 and 3 by adjusting the amount of Sodium Silicate (Na₂SiO₃) solution for the samples. The Samples were casted in 43 mm diameter by 50 mm height cylindrical plastic mould and 50 tapping for each sample to remove the air bubbles from the cast. The casted samples curing at 60⁰ C for 24 Hr in oven and de-mould it. Samples wrapped within plastic zip bags to prevent moisture loss and then stored at 35⁰ ± 2⁰C for dry curing temperature until the samples were tested.

Compressive strength Test:

Compressive strength of prepared samples was determined according to the ASTM test methods for compressive strength. Compression testing machine (AIMIL COMPTTEST 2000, India) was used to test the compressive strength of the samples using the loading rate of 90kN/min. Total maximum load were recorded at the point of fracture and the compressive strength is determine by the formula $C_s = F/A$, where C_s is the compressive strength in MPa, F is the total maximum load in Newton and A is the area of loaded surface in mm². Compressive strength was determined on triplicate specimens after 3, 7 and 28 days of curing at 35⁰C

temperature using Automatic Compressive Testing Machine (AIMIL COMPTEST 2000, India).

Table 1. Chemical composition of Fly Ash, Bottom Ash & Blast furnace slag

Oxides	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	LOI
Fly Ash	51.06	29.71	9.60	2.14	0.75	0.56	0.04	-	-	0.60
Bottom Ash	51.71	16.20	13.7	3.61	1.56	0.39	0.05	-	-	4.04
GBFS	32.97	17.97	0.72	35.08	10.31	-	-	0.06	0.46	0.58

Table 2: Fines of Bottom ash.

Sieve No.	Mesh Size	Retained Wt. (%)
+229 μ	+ 50 #	22.6
-229μ, +149 μ	-50 #, + 100 #	34.9
-149μ,+74 μ	-100 #, + 200 #	25.7
-74μ, +44 μ	-200 #, + 325 #	7.5
-44 μ	- 325 #	8.1

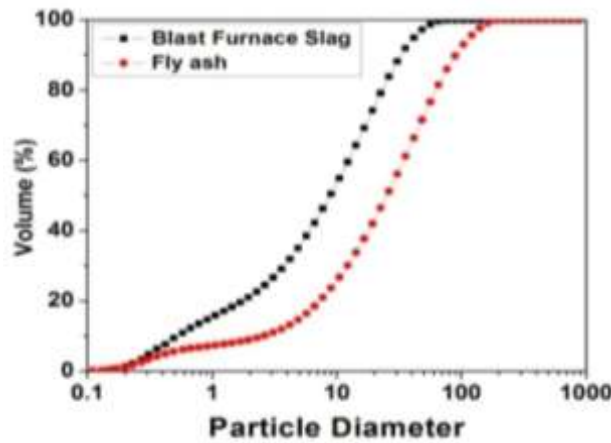


Fig-1: PSD of FA and GBFS.

Table 3: Mix proportions of the samples

Mixture Sample no.	Fly ash (%)	Bottom ash (%)	GBFS (%)	NaOH (%)	Na ₂ SiO ₃ (%)	Si/Al ratio (%)	Water (%)
A	50	30	16	4	NA	2	36
B	48	30	16	6	NA	2	36
C	46	30	16	8	NA	2	36
D	50	30	16	4	28.043	2.5	17.5
E	48	30	16	6	26.453	2.5	17.5
F	46	30	16	8	24.874	2.5	17.5
G	50	30	16	4	44.835	3	7.5
H	48	30	16	6	43.041	3	7.5
I	46	30	16	8	41.248	3	7.5

Lime reactivity test

(IS 1727 - 1967) covers the procedure for determining the reactivity of Fly ash and Bottom ash (Pozzolanic Material) with hydrated lime. Lime reactivity test shows that bottom ash has very poor reactivity. Therefore, it is used as filler material in the preparation of concrete, mortar, and brick (building material).

XRD studies:-

X- ray diffraction (XRD) pattern of raw materials and product were collected by powder X- ray diffraction technique by SIEMENS X- ray diffractometer (model D - 500), using Cu K α radiation with Fe filter. The data was collected using a normal 2 θ step size of 0.3 $^{\circ}$ / Sec and the sample were scanned from 10 $^{\circ}$ - 80 $^{\circ}$ for determination of phases present in the raw materials.

Conduction Calorimeter:

Isothermal conduction calorimeter was used to monitor the stages related to hydration of raw material mixture at constant temperature for the formation of geopolymerization.

Result & Discussion:

The physical properties of the raw material, fly ash, bottom ash and granulated blast furnace slag are given in table 4.

Table 4. Physical property of raw material

Samples	Colour	form	Plasticity	Specific gravity	Particle size d_{50} (μm)
FA	Gray	Powder	Non plastic	1.97	25.20
BA	Dark gray	Granular	Non plastic	1.95	--
GBFS	Light gray	Granular	Non plastic	2.88	8.83

To study the effect of Si/Al ratio and percentage of alkali (NaOH) on geopolymerisation mechanism isothermal conduction calorimeter was used under two different temperature i.e. at 27 °C and at 55 °C. Figure 2 shows the heat evolution curve obtained by Isothermal conduction calorimetry (ICC) of the sample at 27 °C for 17 h and figure 3 shows the heat evaluation curve obtained by ICC of the sample at 55 °C for 20 h. In all these cases, the first peak (which appears more

like a straight line) in the beginning corresponds to the wetting and partial dissolution of glassy content followed by small induction period as a consequence of low reactivity. The second exothermic peak after induction period may be associated with dissolution-precipitation reactions, constituting mainly of the formation of hydrated aluminosilicate gel, and hydrated calcium-silicate gel.

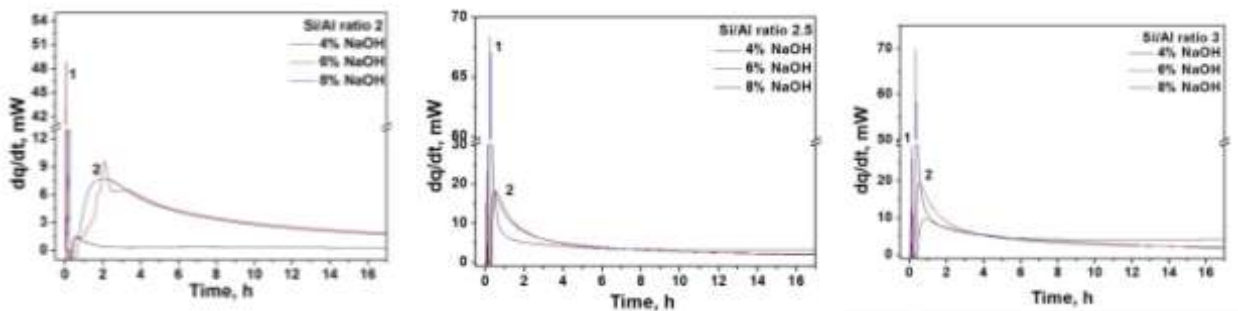


Fig. 2: Study on reactivity of geopolymer at 27 °C through Isothermal conduction calorimetry.

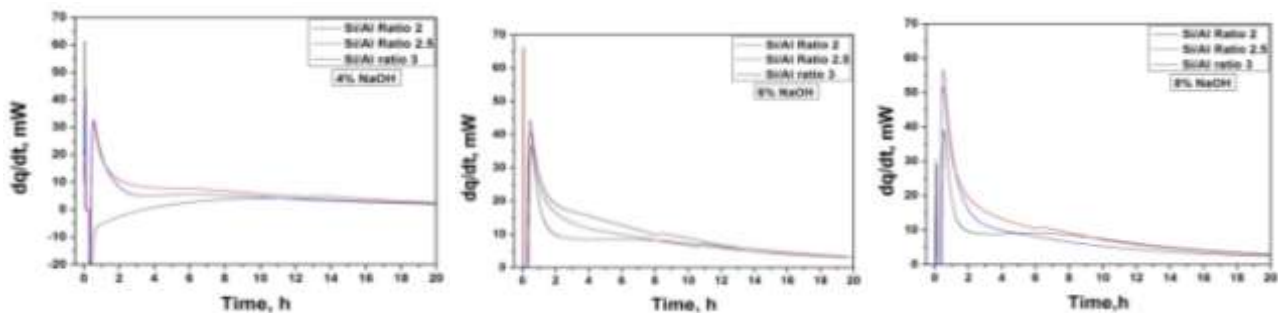


Fig. 3: Study on reactivity of geopolymer at 55 °C through Isothermal conduction calorimetry.

In these cases only the second peak corresponds to the observed geopolymerisation. Similar to the results at 27 °C, the maximum rate of heat evolution increased with increasing NaOH percentage and increasing Si/Al ratio. The prominent trend at 55 °C was due to the combined effect of temperature conditions and NaOH percentage which accelerated the geopolymerisation reactions. All the experimental results show that an increase in Si/Al ratio and alkali

(NaOH) percentage addition leads to increase in peak intensity. In figure 2 and 3 the maximum rate (dq/dt) of the reaction was found in Si/Al ratio 3 and alkali percent 8.

Compressive strength:

The result of compressive strength test of geopolymer samples are summarized in table 5 and fig. 4.

Table 5: Compressive strength results

Sample no.	CS(After3 Day)	CS(After7 Day)	CS(After 28 Day)	NaOH %	Si/Al Ratio
A	4.1	5.1	6.0	4	2
B	4.5	5.4	6.3	6	
C	4.6	5.6	6.8	8	
D	10.86	16.66	19.89	4	2.5
E	11.29	17.76	21.20	6	
F	12.80	21.61	26.02	8	
G	16.60	22.90	26.71	4	3
H	18.60	24.90	28.40	6	
I	20.8	31.20	35.31	8	

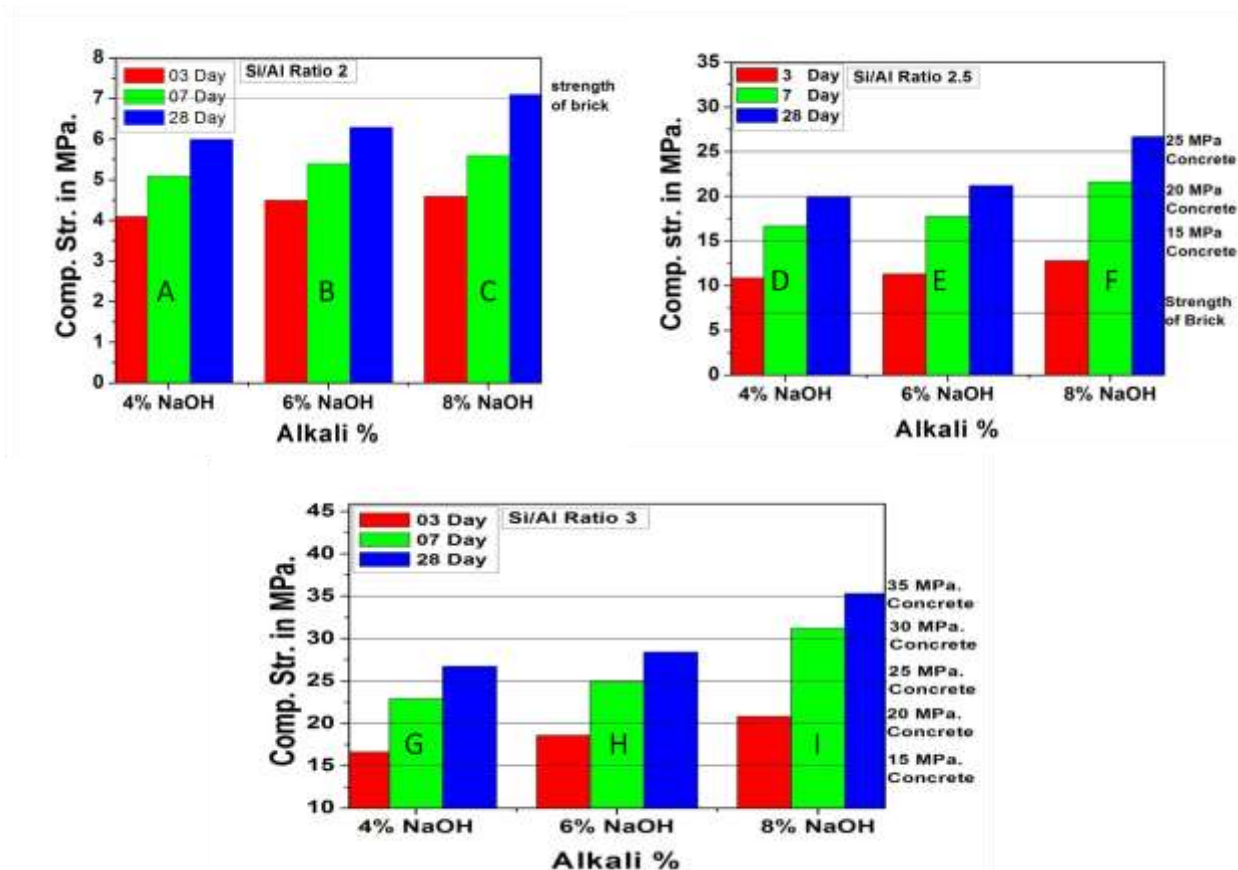


Fig.4: Compressive strength results of samples.

Compressive strength of the samples after curing is shown in fig. 4. In all the cases, compressive strength increases with increased with increase in Si/Al ratio and with increasing in NaOH (alkali) %. The compressive strength value is higher in samples with higher Si/Al ratio and high alkali % (i.e. Si/Al ratio 3 and alkali % 8).

XRD:-

Mineralogical characterisation was carried out by XRD. Figure 5 showed crystalline quartz and mullite phases, which derived from parent fly ash and bottom ash. The products formed due to reaction between reactive glassy fraction of fly ash, bottom ash and GBFS. It is worthwhile to mention here that the glass

content of the fly ash and bottom ash consisted of reactive glasses, and only reactive glasses participates in geopolymerisation. The hump between 10^0 to 30^0 were found in all cases which indicate the formation of low crystalline gel phase corresponding to A-S-H and C-S-H.

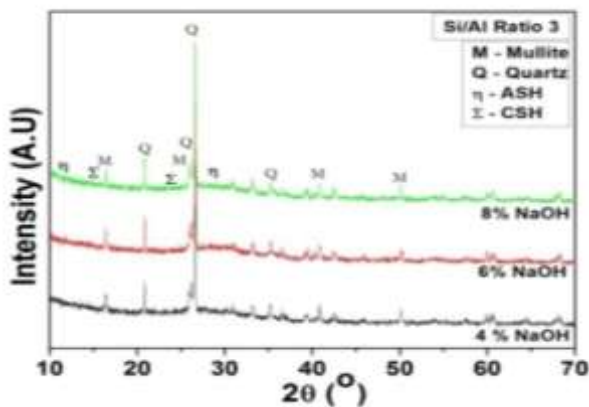


Fig. 5: X- Ray pattern of Geopolymer Samples.

Furthermore, under the same scan conditions, this hump is more pronounced for increased NaOH geopolymer, indicating higher geopolymer content. As such, the geopolymer made with higher NaOH content possesses higher strength and stiffness, which is consistent with the mechanical testing results. Duxson also reported that higher concentration of reactive Si in the geopolymerisation process typically leads to a higher compressive strength. With increase in NaOH %, the peak intensity of crystalline phases decreased. This is probably enhanced dissolution of crystalline peaks in higher alkali concentration.

Conclusion

Geopolymerisation behaviour of fly ash and bottom ash were studied with addition of granulated blast furnace slag. It was observed that fly ash has pozzolanic reactivity as well as reactivity with alkaline solution. However bottom ash mostly behaved as inert aggregate especially during early geopolymerisation reaction. Addition of granulated blast furnace slag has enhanced the rate of geopolymerisation by precipitation of C-S-H gel. Geopolymer composite can be prepared by synergistic geopolymerisation of fly ash and bottom ash at ambient as well as elevated temperature. The desirable ambient temperature is 35^o C and elevated temperature is 55^o C. The rate of geopolymerisation was found dependable on the following three parameters (a) curing temperature, (b) Si:Al ratio and (c) alkali concentration. The strength development was guided by the formation of compact microstructure with reinforcement of gel structure with unreacted grains. EDAX analysis revealed that geopolymer samples with GBFS are dominated by both A-S-H and C-S-H gel co-

existed. In different types of batch composition, different strength has been reported. Based on compressive strength data, composition C and D were found suitable for brick making, composition E for M20 grade concrete F, G and H for M25 grade concrete, and composition I for M35 grade concrete. In addition to suitable mechanical properties, it is assumed that the building products such as brick and concrete will be more sustainable in terms of environment performance, economic viability and potential for waste utilization.

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