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Process Parameters affecting Setting time and Mechanical Properties of Ambient Cured Alkali Activated Fly Ash and Bottom Ash Concrete

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Abstract

Sustainable materials are the demand of the world today, as sustainability of material is very crucial for the progress of society. It is this very need, which initiates the quest for the suitable alternative to cement, with similar properties as cement. Since safe and effective disposal of industrial waste is also very crucial, alkali activated concrete seems an ideal solution to achieve both the objectives. The present scope of study involves a combination of fly ash and bottom ash to prepare alkali activated concrete at ambient curing. Sodium based alkaline activators were used during the investigation. Process parameters like source material variation, amount of alkaline admixture, variation of sodium silicate to sodium hydroxide ratio, variation of alkaline solution to cementitious material, admixture dosage and amount of extra water were investigated. Observations indicate that increase in bottom ash content from 40% to 60% lead to decrease in compressive strength of concrete on the other hand increase in the amount of Sodium Hydroxide activators from 10 M to 14 M lead to increase in compressive strength. Compressive strength

increased from 30.5 to 33.3 MPa when alkaline ratio increased from 1.5 -2.5.

Keywords: Compressive strength; sustainability; ambient curing, fly ash, bottom ash, alkaline solution, admixture

Introduction

Due to tremendous rise of industrial establishments demand for power generation has increased by leaps and bounds. Also with the increase in world population and their rise in living standards, there has been an exponential increase in the use of building material today, particularly concrete. Today, in most developing countries the power requirements are still coal-dependent, resulting in a huge quantity of fly ash and bottom ash as residue. Estimates peg that over 600 Mt of coal ash is produced per annum, of which of which only 50% is utilised while rest is dumped as landfill [1]. This results in polluting of land, water and air leading to irreparable damage to the environment [2, 3]. These industrial waste thus needs to be judiciously used. Industrial waste produced in large quantities includes fly ash, bottom ash, red mud, slag and metakaolin. Alkali activated concrete is considered to be the most promising alternative to cement concrete. Alkali activated concrete makes use of any industrial waste which is rich in silica and alumina ions. They are polymerised into long chain of molecules to form a three-dimensional ring like structure of Si-O-Al-O [4] when activation is done with alkaline solution. These solutions can be hydroxides of sodium or potassium or combination of hydroxides and silicates of sodium and potassium. A lot of studies have been carried out on alkali activation of fly ash and it has been found that fly ash based alkali activated concrete has good mechanical properties as well as excellent durability properties in terms of acid resistance, thermal resistance and corrosion resistance [5-7] as compared to ordinary Portland cement concrete. It is well-known fact, that initial curing at elevated temperature increases the reactivity of fly ash and leads to the higher development of strength [8-10]. Bottom ash, on the other hand, even though obtained from the same source as fly ash is not widely utilised as fly ash. Bottom ash is collected from the bottom-most part of an incinerator and is often discharged with water in to the pond and termed as 'pond ash'. As bottom ash particles are large and irregular in shape and they have less glassy phase compared to fly ash, their reactivity is low and does not provide required compressive strength. The use of bottom ash as the cementitious material is thus very less [11- 13]. Xie and Ozbakkaloglu [1] carried out work on the ambient cured bottom ash and fly ash concrete. It was observed that workability of geopolymer concrete was directly related to the mass ratio of fly ash and bottom ash and did not observe any exothermic reaction in form of temperature rise in case of geopolymer concrete. Generally, bottom ash is disposed in a landfill and could cause damage due to leaching of poisonous materials into the ground water.

2. Research Significance

To date, most of studies carried out using fly ash and bottom ash for alkali activation have focussed on studying microstructure, phase analysis, reaction process for paste or mortar. Also, as discussed previously mostly due to coarser nature of bottom ash, the majority of researchers have finely grounded the bottom ash in order to increase its reactivity [11-15]. The purpose of present investigation is to evaluate properties of alkali activated fly ash/bottom ash blended concrete which is manufactured at ambient temperature. Investigation of properties like consistency and setting time of paste, compressive strength, microstructure studies, split tensile strength and flexure strength of concrete will be carried out. Parameters affecting compressive strength will be investigated which will help in the determination of identifying key factors controlling strength. One of the drawbacks of alkali activated concrete is it requires the initial high temperature to achieve strength, which is not feasible in practical application. Hence, in the present investigation ambient curing was used as it is the most feasible technique for curing concrete in tropical climates. Bottom ash was not finely ground but was utilised in pristine condition, considering that it is not possible and economical to grind the bottom ash when used for field application.

3. Experimental Program

3.1 Materials used

3.1.1 Source Material

Both, bottom ash and fly ash- Low calcium class F, was procured from Torrent Power plant, a local thermal power station at Gandhinagar, Ahmedabad. The chemical composition of bottom ash and fly ash are given in Table 1. Scanning microscope images of fly ash and bottom ash is shown in Figure 1. As observed from Figure 1 (A), fly ash particles are perfectly spherical in nature while Figure 1(B) shows bottom ash particles as angular and coarser in size. Hence during alkali activation process much of reaction in the initial phase is due to reactivity of fly ash particles. Particle size distribution is shown in Figure 2. Fly ash was observed to be much finer than bottom ash.

Table 1: Chemical Properties of fly ash and bottom ash

Sr. No	Compound	Fly Ash (%)	Bottom Ash (%)
1	SiO_2	61.4	66.15
2	Al_2O_3	-	30.76
3	Fe_2O_3	-	0.5
4	$SiO_2 + Al_2O_3 + Fe_2O_3$	93.02	97.41
5	CaO	0.9	0.90
6	Reactive Silica	34.36	-
7	MgO	1.42	0.44

8	SO_3	0.56	0.03
10	Loss of Ignition	1.05	1.17

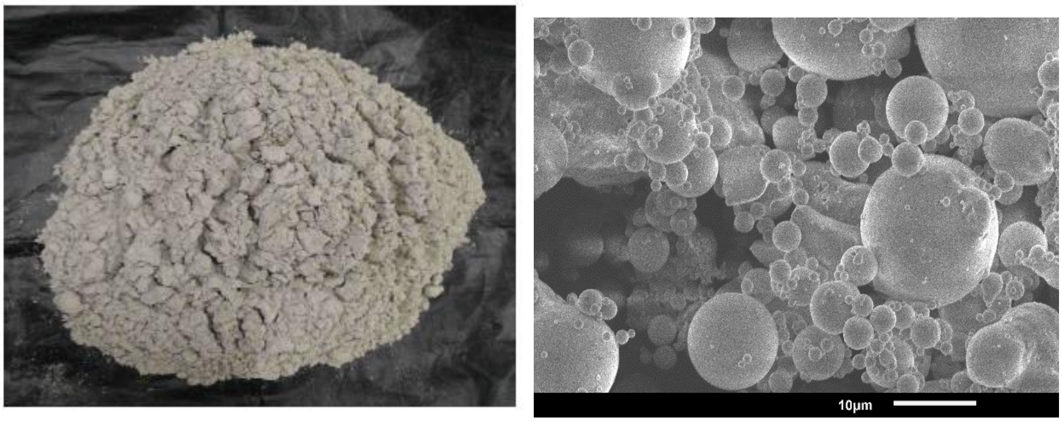


Figure 1: (A) Fly ash and its SEM image used in this investigation (Gandhinagar Power Plant)

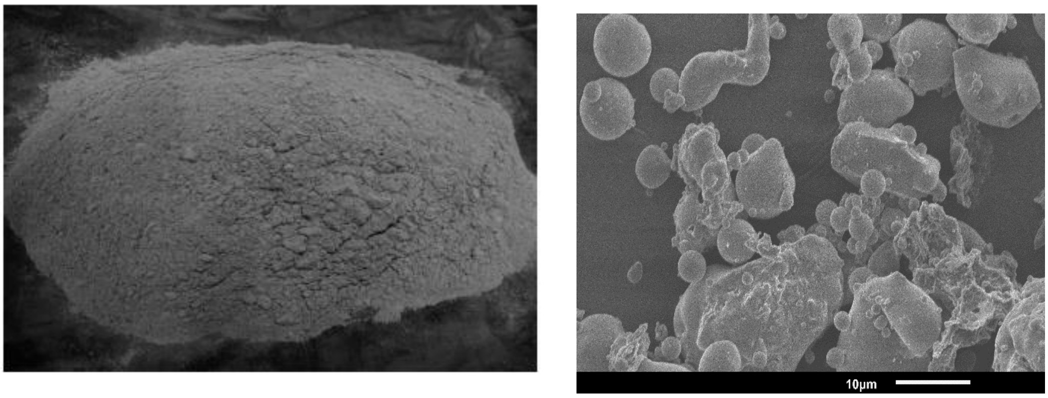


Figure 1(B): Bottom Ash and its SEM image used in this investigation (Gandhinagar Power Plant)

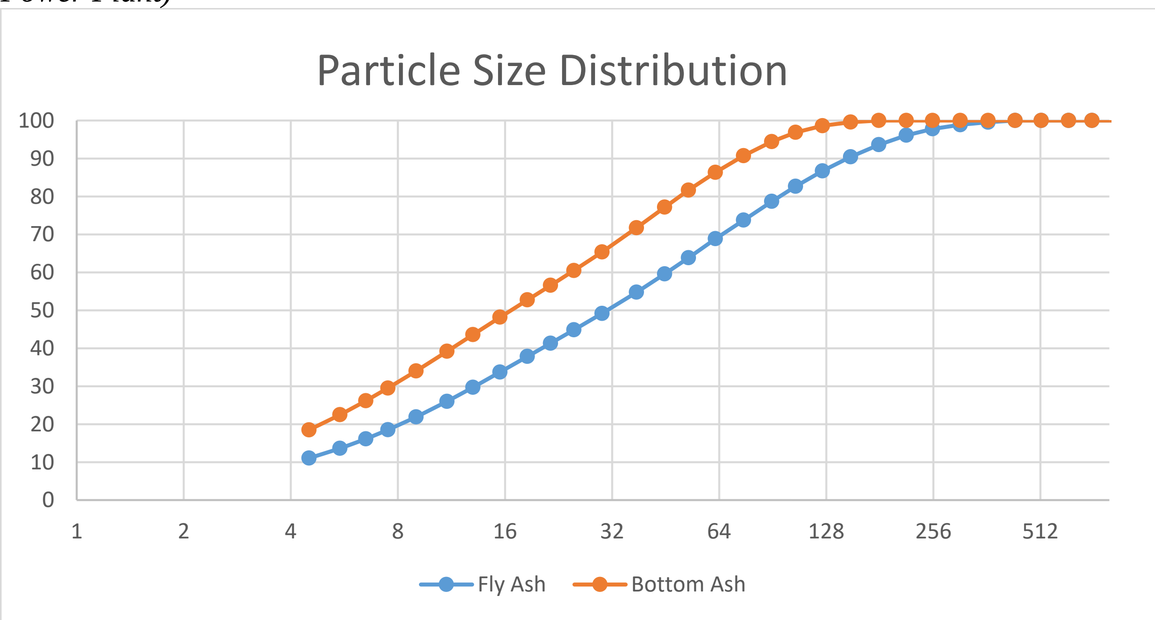


Figure 2: Particle Size Distribution curve for fly ash and bottom ash

3.1.2 Alkaline activators

Sodium hydroxide and sodium silicate were used as alkaline activators. Sodium hydroxide was in flakes form with 98% purity. It was of industrial grade and was mixed in predetermined weight in ordinary tap water depending on molarity of sodium hydroxide (NaOH) used. For e.g. for 10M NaOH solution the amount of flakes taken were 40*10 = 400 gm and were further reduced depending on the density of solution [6]. Sodium silicate with the specific gravity of 1.58 and the modular ratio of 2.23 (Na_2O=15.53% and SiO_2=35.42%) was used for investigation. The alkaline activator solution was prepared and left to rest for a day before being used in concrete. Casting and curing both were done at room temperature.

3.1.3 Aggregates

Preparation of concrete was done by a judicious combination of coarse and fine aggregates. Gravel of 10mm and 20mm size was used to as coarse aggregate. Fineness Modulus of 20mm aggregate was 7.3 while for 10 mm aggregate was found to be 6.03. Coarse aggregate had the specific gravity of 2.7 and it confirmed to IS:2386 (1963) [16] specification. River sand was used as fine aggregate having the specific gravity of 2.6 conforming to Zone II with fineness modulus of 3.5 and confirmed to IS:383 (1970) [17].

3.2. Mixture Design

3.2.1 Alkali Activated Paste

Paste samples were tested for consistency and setting time. Sodium hydroxide solution was prepared one hour prior to casting. Fly ash and bottom ash were thoroughly mixed alkaline solution of sodium hydroxide and sodium silicate as shown in Table 2 to form a homogenous paste.

Table 2: Mixture proportion for standard consistency test

rail No.	Fly Ash (gm)	Bottom Ash (gm)	NaOH (M)	Na_2SiO_3/ NaOH	% of solution
Trial 1	500	-	12	1.5	25
Trial 2	500	-	12	1.5	35
Trial 3	400	100	12	1.5	35
Trial 4	300	200	12	1.5	35
Trial 5	250	250	12	1.5	35
Trial 6	200	300	12	1.5	35
Trial 7	100	400	12	1.5	35
Trial 8	-	500	12	1.5	35

3.2.2. Alkali Activated Concrete

Mixture design of alkali activated concrete was done using density method as described in previous literature [6]. The density of concrete was assumed to be 2400 kg/m^3. For alkali activated concrete, total amount of cementitious material in concrete was kept 445 kg/m^3. Like ordinary Portland cement concrete, it was assumed that 75% of the volume was taken by aggregates. The proportion of coarse aggregate of 20 mm and 10 mm was kept as 60:40. Amount of coarse aggregate was 1179 kg/m^3, while the amount of fine aggregate was 630 kg/m^3. The naphthalene based admixture was added to have proper workability in concrete. Concrete was prepared by first dry mixing both coarse and fine aggregate in a pan mixture with 75L capacity. After this source material was added all the while being subjected to uniform mixing. The solution of sodium hydroxide, sodium silicate and superplasticizer was added to enhance workability. Wet mixing was done for four to five minutes till a uniform consistent mixture was obtained. To improve the workability small amount of extra water was added. After mixing, the mixture was poured into the moulds and compacted on a vibrating table. Both mixing and compaction were carried out at room temperature. The moulds were allowed to set for a rest period of 2 days, before demoulding. Due to the inclusion of bottom ash, the rest period was increased from one to two days as the concrete did not set after one day. After demoulding, alkali activated concrete was allowed to cure at ambient temperature up to test period. Variations were done in one parameter like proportion of fly ash and bottom ash, source material to alkaline ratio, alkaline solution ratio, amount of source material, amount of super plasticizer and amount of extra water keeping other parameters constant. The variation of parameters for different mixture proportion of the alkali activated fly ash/bottom ash blended concrete are shown in Table 3.

Table 3: Details of proportion of various ingredients of Alkali activated concrete

Mix	Ratio of fly ash : Bottom ash	NaOH (M)	Ratio of Sodium Silicate to Sodium Hydroxide	Ratio of solution to binder	Admixture	Extra water
M 1	90:10	12	2	0.35	1%	10%
M 2	80:20	12	2	0.35	1%	10%
M 3	70:30	12	2	0.35	1%	10%
M 4	60:40	12	2	0.35	1%	10%
M 5	50:50	12	2	0.35	1%	10%
M 6	40:60	12	2	0.35	1%	10%
M 7	60:40	10	2	0.35	1%	10%
M 8	50:50	10	2	0.35	1%	10%
M 9	40:60	10	2	0.35	1%	10%
M 10	60:40	14	2	0.35	1%	10%
M 11	50:50	14	2	0.35	1%	10%
M 12	40:60	14	2	0.35	1%	10%
M 13	50:50	12	1.5	0.35	1%	10%
M 14	50:50	12	2.5	0.35	1%	10%
M 15	50:50	12	2.5	0.30	1%	10%
M 16	50:50	12	2.5	0.40	1%	10%
M 17	50:50	12	2.5	0.35	1.5%	10%
M 18	50:50	12	2.5	0.35	1%	15%
M 19	50:50	12	2.5	0.35	1%	20%

3.3 Casting of Specimens

Consistency and setting time was measured for alkali activated paste using Vicat's apparatus according to ASTM C 191-08. Compressive strength was measured by compression testing machine of 200 kN capacity according to IS 516 on 150 × 150 × 150 mm cube. Split tensile strength was measured in cylindrical specimen 150 mm diameter and 300 mm height at 28 days, while flexure test was performed on beams of 100 mm × 100 mm × 500 mm according to IS 516 at 28 days [18].

4. Results and Discussions

4.1 Consistency & Setting time of fly ash bottom ash paste

Consistency test was used to determine the suitable combination of fly ash and bottom ash and to evaluate the amount of extra water required to have proper consistency. In this test fly ash to bottom ash ratio was varied as 100:0, 80:20; 60:40; 50:50; 40:60 and 0:100. In all trials, 12M solution of sodium hydroxide was used with the ratio of sodium silicate to sodium hydroxide as 1.5. Amount of solution added is defined in terms of percentage of fly ash and bottom ash. To determine correct amount of activator initially 25% of the activator solution was taken which yielded 6 mm of penetration when 25% of extra water was used. Thereafter, solution percentage was increased to 35% in subsequent combinations. Table 4 shows results of consistency for various proportion of fly ash and bottom ash. It can be seen that increase in bottom ash content leads to increase in extra water content. Hence, to have maximum use of bottom ash, it was decided to use an equal amount of fly ash and bottom ash.

For an equal proportion of fly ash: bottom ash initial setting time for paste was 100 minutes and final setting time was 2520 minutes. Knowledge of final setting time will enable the user to know stripping time of specimen.

Table 4: Consistency Results

Mix No.	% of solution	Fly Ash (gm)	Bottom Ash (gm)	% of extra water	Penetration depth
Mix 1	25	500	-	25% extra water	6 mm
Mix 2	35	500	-	4% of extra water	5 mm
Mix 3	35	400	100	5.5% extra water	5 mm
Mix 4	35	300	200	6% extra water	5 mm
Mix 5	35	250	250	6% extra water	5 mm
Mix 6	35	200	300	8% extra water	6 mm
Mix 7	35	100	400	9% extra water	5 mm
Mix 8	35	-	500	15%extra water	5 mm

4.2. Effect of variation of bottom ash content on compressive strength of fly ash/ bottom ash blended concrete

As observed in Figure 3, for fly ash : bottom ash ratio for M 1 (90:10) compressive strength was 21.2 MPa and 35.7 MPa which decreased to 19.9 MPa and 33.7 MPa with ratio of 70:30 (M 3) and further decreased to 17.9 MPa and 30.9 MPa at ratio of 40:60 (M 6). It was found that in previous works that though both, fly ash and bottom ash are obtained from the same source, bottom ash is much coarser than fly ash and less reactive compared to fly ash [11 -15]. Reactivity of fly ash is very low at ambient curing [19] and with the addition of bottom ash, it further gets reduced which is as reported in previous studies. Choosing M 25 grade of concrete as mix design grade, tartest strength would be 31.25 MPa. Figure 4, shows the comparison of strength after 7 and 28 days with target strength. It is observed that at 7 days, under ambient curing, 67% of target compressive strength was achieved in M 1, while 57 % of target compressive strength was achieved when bottom ash increases to 60%. Similarly, for M 1 the increase in compressive strength from 7 to 28 days was 68.5% while for M 6, it was 73.4%. Thus, it indicates that an average of 71% increase in compressive strength takes place between 7 and 28 days, implying that as it was ambient curing, polymerisation continues and reaction between source material and alkaline liquid was still under progress. Compressive strength increases gradually up to 28 days and about 100% of target strength of 31 MPa is achieved at equal proportion of fly ash and bottom ash.

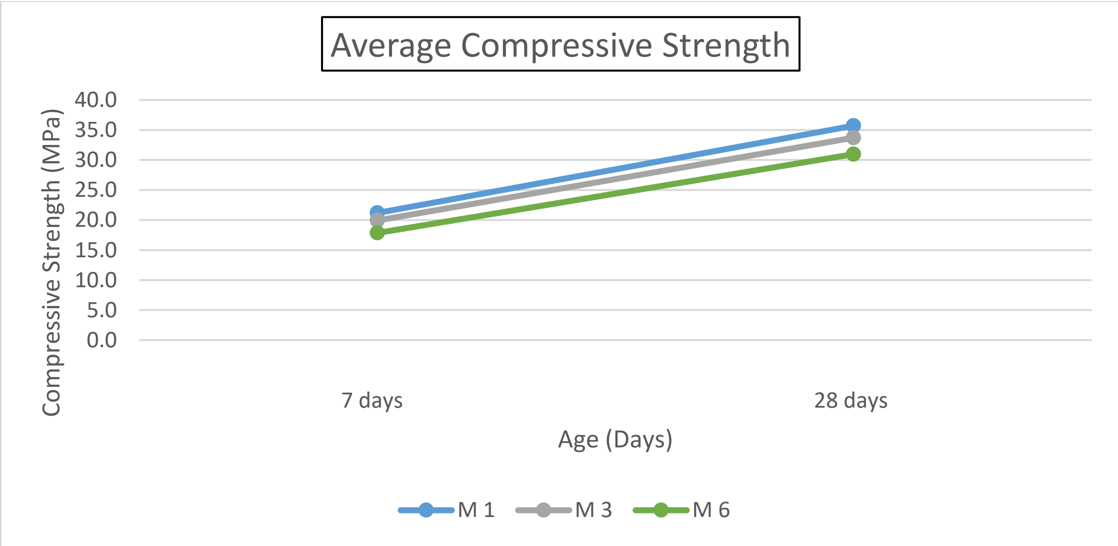


Figure 3: Average Compressive strength at various ages

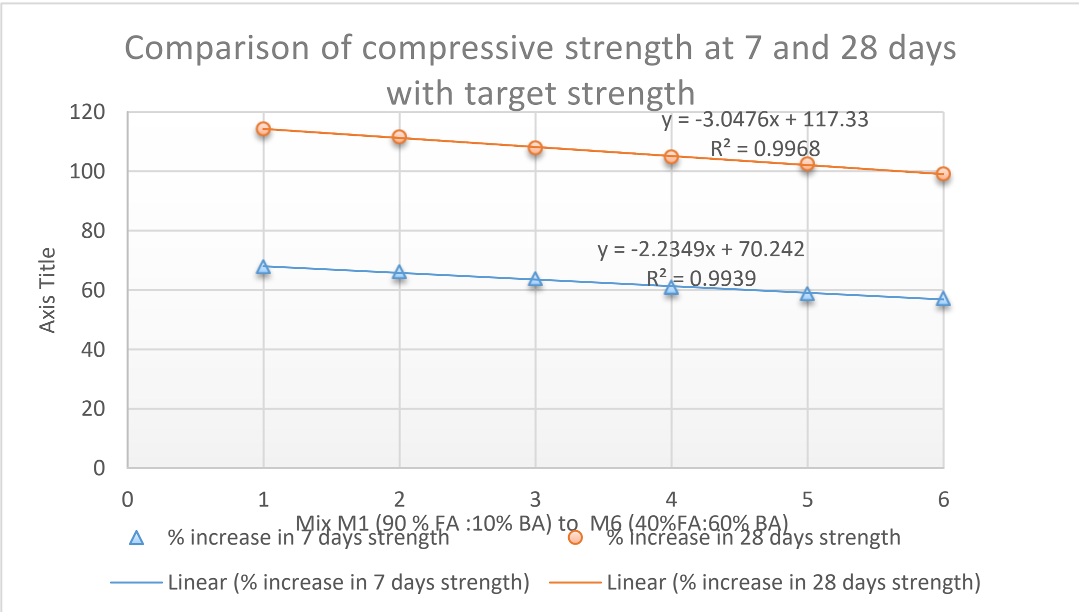
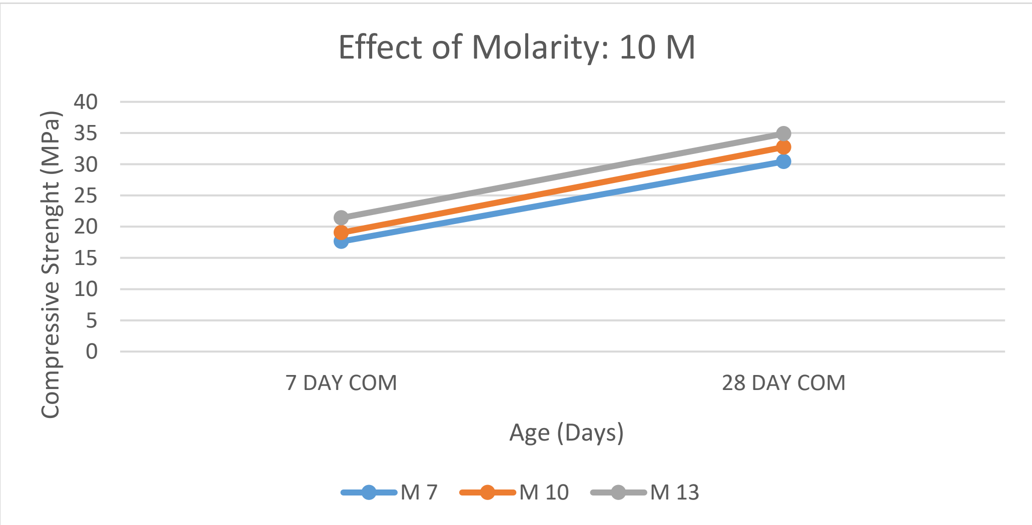
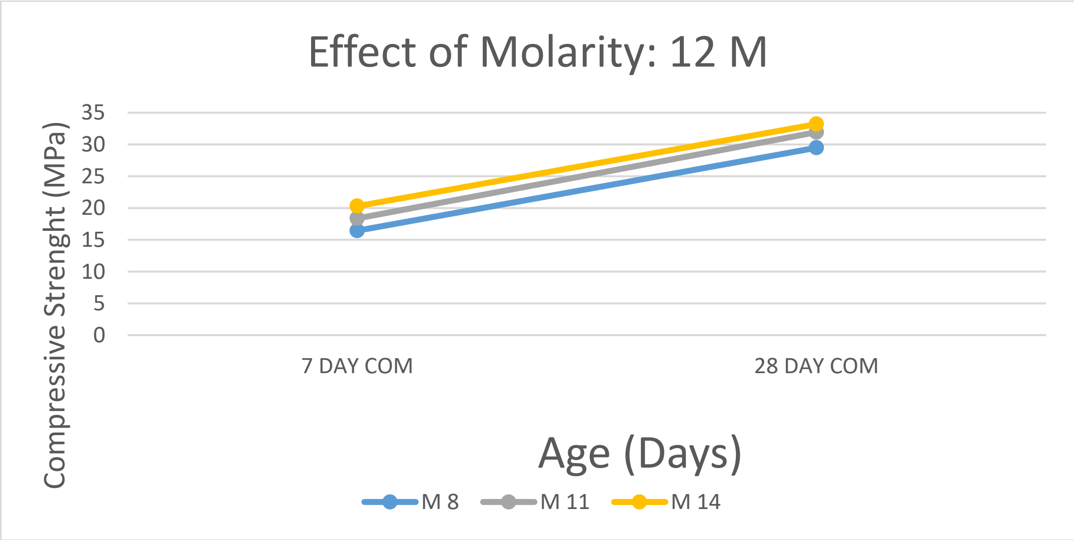


Figure 4: Comparison of 7 and 28 strength with M25 grade concrete

4.3. Effect of Alkaline Activator

Figure 5 (A, B and C) shows compressive strength for three different ratio of fly ash bottom ash 60:40, 50:50, 40:60 with 10M, 12 M and 14 M sodium hydroxide. At 7 days compressive strength increases from 17.63 MPa to 21.41 MPa with an increase in molarity from 10 M to 14 M for Mix M7 to M 9.While for Mix M 13 to M 15, increase in 7 days strength was from 15.4 MPa to 19.9 MPa. Similarly, for 10 M Sodium hydroxide, M 7 had 30.4 MPa which increased to 34.9 MPa and for M 13, the compressive strength was 28.4 MPa which increased to 32.9 MPa at 28 days at 14 M for M 15 mix. It was observed that when molarity changes from 10 M to 12 M, 7.6% , 8.5% and 9.1% increase in compressive strength was observed for Mix 7, 8 and 9 for 7 days ambient curing. For change in molarity from 10 M to 14 M, 14.6%, 16.2% and 14.8% increase in compressive strength was observed in Mix 7, 8 and 9 at 28 days ambient curing. In concrete with higher fly ash content, strength was greater and increased with higher molarity while with the increase in bottom ash, strength was lowered. Increase in strength was due to more amount of alkaline solution available and therefore more reaction of source material leading to increased geopolymerisation.





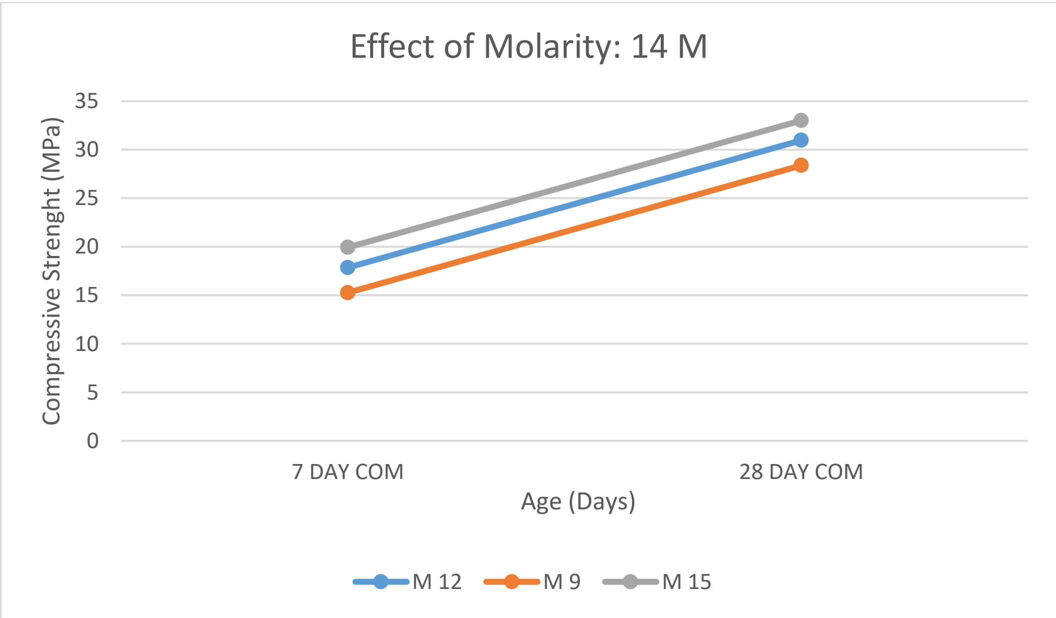


Figure 5: Effect of change of Molarity on 7 days & 28 days compressive strength for various ratios of fly ash& bottom ash

4.4. Effect of activator solution ratio on compressive strength

In order to understand the effect of ratio of sodium silicate to sodium hydroxide, the ratio was varied as 1.5, 2 and 2.5 in mix M 13, M 5 and M 14 for an equal proportion of fly ash and bottom ash as shown in Table 4. As sodium silicate is highly viscous, increase in alkaline liquid ratio increases overall viscosity of the mixture. Due to the presence of soluble silica in alkali activated concrete rate of crystallization was enhanced and hence more condensation took place leading to increased reactivity [20]. As observed in Figure 6, there was 95%, 73.8% and 52.5% increase in compressive strength from 7 days to 28 days with the variation of alkaline ratio from 1.5,2 and 2.5 respectively.

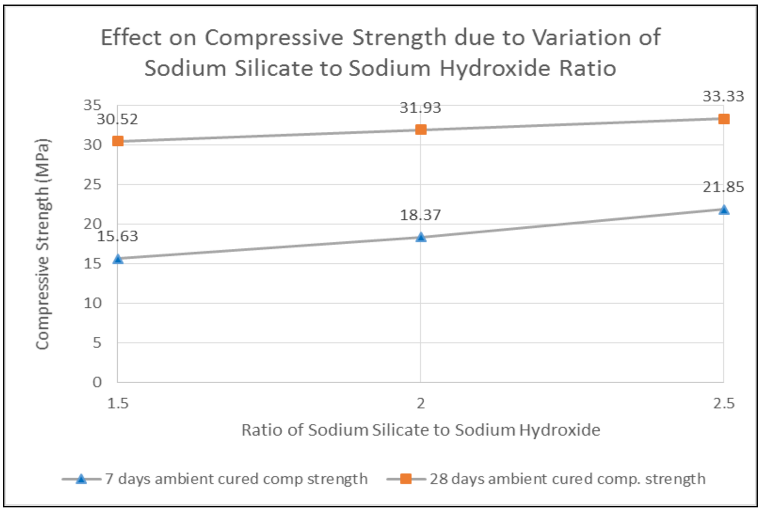


Figure 6: Variation of alkaline ratio

4.5. Effect of alkaline ratio to cementitious material

Figure 7 shows the effect of alkaline ratio to cementitious material on compressive strength for M 15, M 5 and M 16, with alkaline to fly ash ratio of 0.3, 0.35 and 0.4. With the increase in the ratio of alkaline liquid to cementitious material, increase in Na_2O/SiO_2 ratio of mixture increases from 0.10 to 0.12. Higher ratio indicates more amount of alkaline liquid available for geopolymerisation process thereby increasing the reactivity of source material. It can be observed that, increase in alkaline to cementitious ratio by 0.05 increases 7 days compressive strength approximately by 6.5% while 28 days strength by 3%. While, when ratio was increased by 0.1, 13.7% and 5.7% increase in compressive strength was observed at 7 and 28 days respectively. Greater effect was observed on 7 days strength compared to 28 days strength, as there is more alkaline liquid available for forming a chain reaction, leading to the increase in the strength, which in initial phase was very vital.

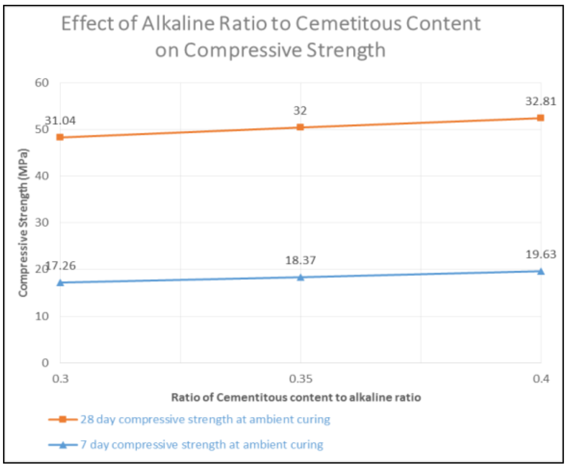


Figure 7. Alkaline ratio to cementitious content

4.6. Effect of Admixture

The literature on alkali activated concrete reveals that directly admixture does not have any role in strength mechanism of alkali activated concrete. But it increases the workability of concrete, which will lead to increase in compaction and hence increase in strength. M 5 and M 17 were tested for two dosages of an admixture of 1% and 1.5% of cementitious material. Figure 8, shows the evaluation of compressive strength at 7 and 28 days, which shows 4.5% at 7 days and 3.5% at 28 days when admixture dosage was increased by 0.5%. Increase in admixture dosage beyond 2% led to decrease in compressive strength in fly ash based concrete [6].

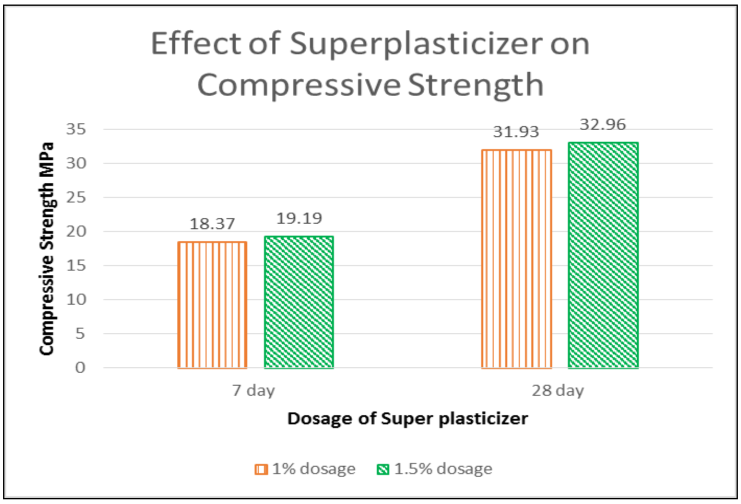


Figure 8. Effect of admixture dosage

4.7. Effect of extra water

To enhance the workability of the mixture, additional water termed as extra water was added to alkali activated concrete. This will allow ease of compaction and make concrete mixture more workable. Three mixes, M 5 with extra water dosage of 10% of cementitious material, M 18 with 15% and Mix 19 with 20% extra water were cast with equal amount of fly ash and bottom ash. Figure 9, shows effect of extra water on compressive strength. It was observed that increase from 10% to 15% of extra water increased 7 days compressive strength by 7.8% and by 4.6% for 28 days, while the decrease in strength occurred when extra water dosage was increased to 20%. This is similar to the increase in water to cementitious material in ordinary concrete where the decrease in strength occurs with increase in w/c ratio.

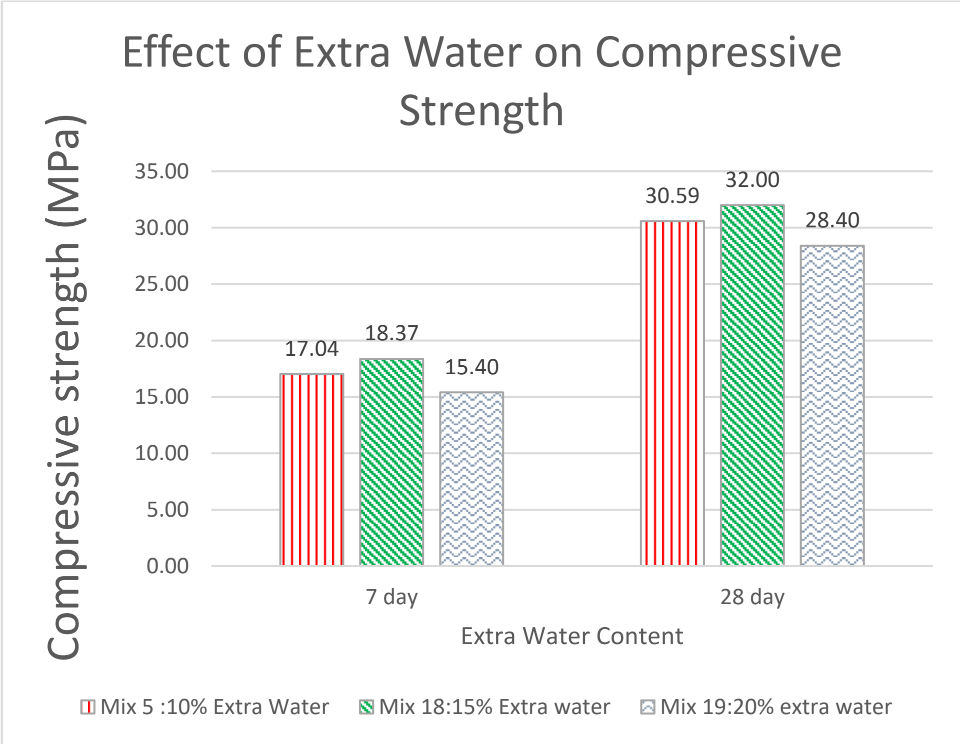
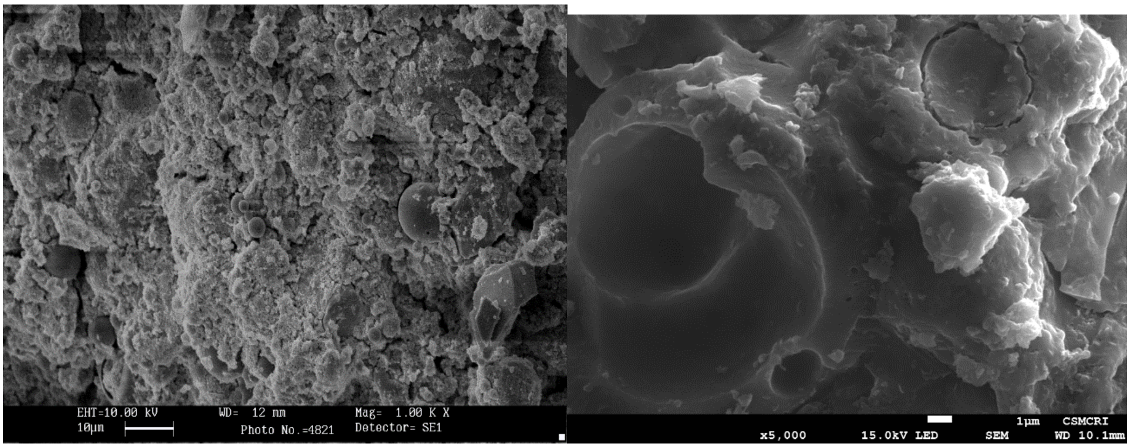
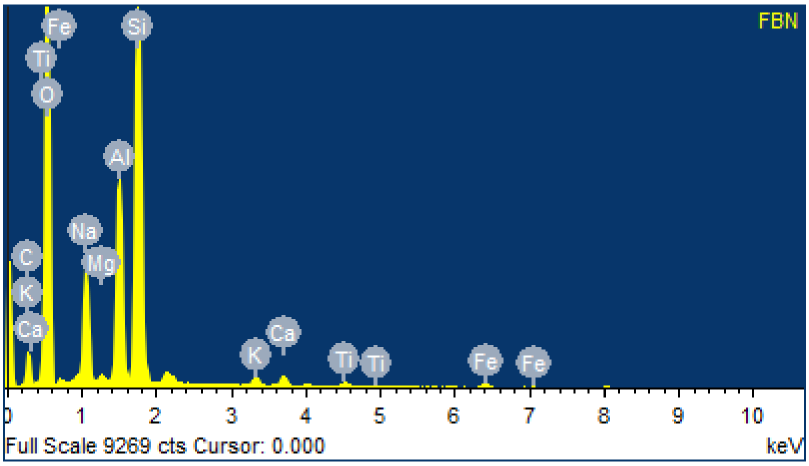


Figure 9. Effect of Extra Water

4.8 Microstructural studies

Scanning Electron Microscope image of fly ash bottom ash blended paste with both source material in equal proportions show that fly ash particles have reacted to a large extent and formed paste while a large amount of unreacted bottom ash particles are seen in the image. The activated product contains SiO_2, Al_2O_3 and Wollastonite with Albite compounds. The alkali activated gel does not have significant traces of calcium which indicated primarily alumina silicate hydrate gel is responsible for reaction products and strength mechanism.





C: $CaCO_3$, O ; SiO_2, Na: Albite , Mg: MgO , Al: Al_2O_3, Si : SiO_2 K: MAD-10 Feldspar Ca: Wollastonite, Ti: Ti, Fe: Fe

Figure 10 : SEM image of Fly Ash and Bottom ash activated at ambient curing

5. Split tensile & Flexural strength of alkali activated concrete with fly ash and bottom ash blend

Flexural strength of alkali activated concrete was tested on 250 kN capacity hydraulic testing machine as per IS:516 (1959) [21] specifications. An average flexural strength of alkali activated concrete with fly ash and bottom ash was 3.73 MPa.

Split tensile strength was evaluated on three cylinders of 150 × 300 mm size after 28 days of respective curing on ordinary as per guideline in IS:516 (1959) [21]. Average of three specimens were taken and was found to be 2.84 MPa

7. Conclusion

Study on alkali activation of fly ash bottom ash has led to following conclusions:

- Increase in bottom ash content in alkali activation led to decrease in compressive strength.
- Increase in Molarity of sodium hydroxide led to increase in compressive strength, with more effect in initial stages. When concentration of sodium hydroxide increases, so optimum dosage will depend upon strength requirement
- Increase in alkaline ratio, increased sodium silicate content leading to more viscous solution and increasing the strength appreciably at 7 days.
- Increase in the alkaline ratio to cementitious material leads to increase in the compressive strength and optimum ratio was 0.35.
- Superplasticizer dosage also has influence on the strength and workability and hence increase in compressive strength but should be optimised to have an economical design.
- Extra water increased workability and hence ease of compaction to a certain extent. But greater increase leads to decrease in compressive strength.

The present investigation shows, that both fly ash and bottom ash being industrial waste can be judiciously used in concrete without applying additional temperature, making alkali activated concrete an attractive option for sustainable and eco-friendly reuse of industrial waste.

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