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PARAMETRIC STUDY ON FLY ASH & BOTTOM ASH BASED ALKALI ACTIVATED MORTAR AND CONCRETE

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Abstract: An attempt has been made to develop cement-less alkali activated concrete using combination of fly ash and bottom ash. This paper aims to examine effect of variation in source materials and other salient parameters on compressive strength. A start has been made by making a fly ash and bottom ash-based alkali activated mortar using river sand. The initial and final setting time and consistency measurements have been recorded for mortar. Suitable mix-proportioning for the alkali activated mortar has been earmarked. Several parameters have been varied related to source materials. This includes ratios of fly ash to bottom ash of 70:30, 50:50 and 30:70. Further, amount of source material in the range of 393 kg/m^3 to 429 kg/m^3 has been varied. Other parameters which have been varied include, alkaline liquid to source material ratio of 0.35 and 0.4; alkaline liquid ratio of 2 and 2.5; concentration of NaOH solution of 8M, 10M, 12M 14M and 16M; addition of super plasticizer of 0% and 1%; extra water content of 10% and 15% and rest period of 1 day and 2 days, respectively. Sodium-based alkaline activators have been used for the activation process. The compressive strength at an age of 7 days and 28 days has been evaluated. Ambient curing has been used for all concrete mixes. Test results show satisfactory strength attainment of the alkali activated concrete using substantial amount of bottom ash in addition to fly ash as the source material at a lower concentration of NaOH solution under ambient temperature.

Keywords: Alkali activated concrete, fly ash, bottom ash, compressive strength, sustainable material, cement-less concrete

1. INTRODUCTION

Concrete is the most commonly used construction material in the world due to its properties such as strength, mouldability and availability of its ingredients. Cement is conventionally used as the primary binder to produce concrete, however there is environmental impact associated with the production of cement. The amount of the carbon dioxide released during the manufacture of cement due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of cement produced [1]. Hence, it is imminent to find an alternative binder system to the commonly used and most expensive and most resource consuming Portland cement. In addition, huge quantities of fly ash and bottom ash are generated around the globe from thermal power plants and generally dumped in low level areas. The abundant availability of fly ash and bottom ash worldwide creates an opportunity to utilize this by-product of burning coal, as substitute for Portland cement to manufacture concrete. Because of unique properties such as high early strength, low shrinkage, sulphate and corrosion resistance alkali activated concrete become a viable alternative to conventional cement and hence substantially reduce CO_2 emission caused by the cement and concrete industries. These new concretes utilize industrial wastes in the form of fly ash and bottom ash which are activated by alkaline medium to produce ambient temperature cured inorganic polymeric binder called alkali activated concrete in the form of aluminosilicates. Aluminosilicate materials are typically found in rich in by-product materials such as fly ash, bottom ash, slag, rice-husk ash, red mud, etc. Alkaline liquids are soluble in nature and have either sodium and potassium base [2].

2. LITERATURE REVIEW

Hardjito & Rangan [3] investigated the effect of various parameters on the compressive strength of fly ash-based alkali activated concrete. Addition of naphthalene-based super plasticizer improved the workability of fresh concrete, however, no significant effect was observed on the compressive strength of the hardened concrete. It was suggested to use naphthalene sulphonate based super plasticizer up to 2% to improve the workability of fresh low-calcium fly ash based alkali activated concrete. Longer curing time improved the compressive strength. The strength gain was a maximum when the rest period was three days; beyond that very little further strength gain was attained. Ahmed & Nuruddin [4] investigated the compressive strength of low calcium fly ash-based alkali activated concrete. Longer curing time improved the compressive strength of concrete. Addition of water also improved the workability of concrete mixtures. However, the addition of water beyond a certain limit resulted in bleeding and segregation of concrete and decreased its compressive strength significantly.

Raijiwala et al. [5] studied the effect of salient parameters affecting the properties of low-calcium fly ash-based alkali activated concrete at varied concentrations of alkaline solutions. Higher ratio of sodium silicate to sodium hydroxide by mass improved compressive strength of alkali activated concrete. Increase in curing temperature of 30°C to 90°C, the compressive strength of the alkali activated concrete increased. Also, longer curing time in the range of 4 hours to 96 hours resulted into the higher strength. Mathew et al. [6] conducted an experimental study on the use of fly ash, bottom ash and Ground Granulated Blast Furnace Slag (GGBS) for alkali activated concrete. Sodium hydroxide, sodium silicate activators were used. Bottom ash-GGBS based alkali activated concrete resulted into very low strength as compared to fly ash-GGBS based concrete due to large particle size.

The literature review presented the opportunity to explore various combinations of source materials; parameters to be varied and to be kept constant throughout investigations as well as the curing condition to be employed, etc. Accordingly, the scope of work of the present investigation comprises of evaluation of compressive strength of alkali activated concrete with variation in source materials and other required salient parameters. The use of bottom ash in combination with fly-ash and ambient curing of concrete makes this study unique.

3. EXPERIMENTAL PROGRAMME

3.1 Materials

3.1.1 Aggregates

Locally available 10 mm down size crushed aggregates are used as coarse aggregates and river sand is used as fine aggregates. Physical properties of the aggregates are given in Table 1.

Table 1 : Properties of aggregates[10, 11]

Material	Loose Bulk Density (kg/m^3)	Compact Density (kg/m^3)	Specific Gravity
Sand	1532	1671	2.57
Aggregate (10 mm down)	1348	1509	2.73

3.1.2 Fly ash and Bottom ash

Physical and chemical properties of class F fly ash and Bottom ash given by the supplier and utilized for the production of alkali activated concrete is summarized in Table 2.

Table 2 : Physical and chemical properties of fly ash and bottom ash

Parameters	Unit	Fly ash	Bottom ash	Specifications IS: 3812[9]
Fineness Specific Surface by Blain	m^2/kg	416.36	332.94	Min. 320.0
Passing on 45 Micron Sieve (Wet Sieving)	%	82.37	88	Min. 66.0
Retention on 45 Micron Sieve (Wet Sieving)	%	17.63	22	Max. 34.0
Pozzolanic Activity Index	%	88.23	85.08	Min. 80.0
Total Sulphur as Sulphur Trioxide (SO_3)	%	0.56	0.03	Max. 3.0
Available Alkali as Sodium Oxide (Na_2O)	%	0.62	-	Max. 1.5
Silicon Dioxide as SiO_2	%	61.40	66.15	Min. 35.0
$SiO_2 + Al_2O_3 + Fe_2O_3$	%	93.02	97.41	Min. 70.0
Reactive Silica	%	34.36	-	Min. 20.0
Magnesium Oxide (MgO)	%	1.42	0.44	Max. 5.0
Total Chlorides	%	0.03	-	Max. 0.05
Loss on Ignition	%	1.05	1.17	Max. 5.0
Moisture	m^2/kg	0.10	-	Max. 2.0

3.1.3 Alkaline Liquid

The alkaline liquid used in the present study is a combination of sodium hydroxide and sodium silicate solution. Sodium hydroxide (NaOH) in flakes form with 98% purity purchased from local chemical supplier is used. Properties of the sodium hydroxide and sodium silicate are given in the Table 3.

Table 3 : Details of sodium hydroxide and sodium silicate

Sodium hydroxide		Sodium silicate	
Properties	Value	Properties	Value
Sodium hydroxide (purity)	98.0	Colour	Colourless
Chloride(%)	1.0	Bulk density	1.656gm/cm
Silicate(%)	0.01	Na_2O	16.73%
Na_2Co_3	0.01	SiO_2	36.63%
Nitrate(No_3)	0.005	Total solid content	53.36%
-----		Matter insoluble in water	0.10%

3.1.4 Superplasticizer

To improve the workability of the fresh alkali activated concrete, Polycarboxylic ether based superplasticiser has been used for selected alkali activated concrete mixes. Initially superplasticizer used is 1% by weight of source material based on literature review. Properties of superplasticizer are summarized in Table 4.

Table 4 : Details of superplasticizer

Properties	Value/Observation
Appearance Colour	Pale yellow
Specific Gravity	1.02 at 25◦ C
Chemical name of the active ingredient	Polycarboxylic Ether (12.03%)
Air Entrainment	2% additional air
Chloride Content	Nil

3.2 Preparation of Alkaline Solutions

In this investigation, the compressive strength of alkali activated concrete is examined for the mixes of 8M, 10M, 12M, 14M and 16M Molarity of sodium hydroxide. For instance, NaOH solution with a concentration of 14M consisted of 14x40 = 560 grams of NaOH solids in flake form per liter of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids is measured as 400 grams per kg of NaOH solution of 14M concentration [8]. Note that the mass of NaOH solids is only a fraction of the mass of the NaOH solution, and water has been the major component.

3.3 Procedure of Casting and Curing of Mixes

Fine aggregate, coarse aggregate, fly ash and bottom ash are mixed in dry condition in a pan mixer for 3-4 minutes. The alkaline solution which is a combination of sodium hydroxide and sodium silicate is added to the dry mix. Water is taken as 10% of the cementitious material i.e. combination of fly ash and bottom ash. The mixing is done for about 6-8 minutes for proper bonding of all the materials. After the mixing is done, steel moulds are used for casting alkali activated concrete in three layers. Each layer is given 25 to 35 manual strokes using 20 mm rod for compaction of the specimens. The specimens are vibrated using vibration table for another 10 to 15 seconds. The top surface is leveled using trowel. The sides of the moulds are struck by using hammer in order to expel air present inside the concrete if any as well as to make the sides smoothened. Ambient curing has been used for all the specimens in the present study. This makes this study innovative as most geopolymers around the world are cured at higher temperatures. In ambient curing, the specimens are left in open atmosphere till their testing day.

3.4 Testing Procedure for Evaluation of Compressive Strength

Compression test was conducted on 70.6 mm × 70.6 mm × 70.6 mm cubes using compression testing machine of 2000 kN capacity as shown in Figure 8 according to IS:516 [12]. Three specimens were cast and tested for each concrete mix to be investigated after 7 days and 28 days, respectively.

4. CONSISTENCY AND SETTING TIME RESULTS OF ALKALI ACTIVATED MORTAR

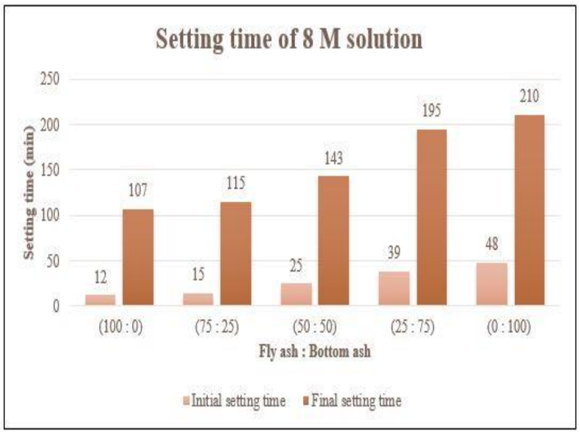
The initial and final setting time of alkali activated concrete is important in practice as it establishes the time available for transport, placing and compaction of concrete [7]. The setting time of the alkali activated fly ash and bottom ash based mortar was measured using a Vicat needle according to IS:4031 [13] and [14]. Five proportions of fly ash and bottom ash 100:0, 75:25, 50:50, 25:75, 0:100, respectively were evaluated. Setting time and normal consistency tests were conducted for all mortar mixes.

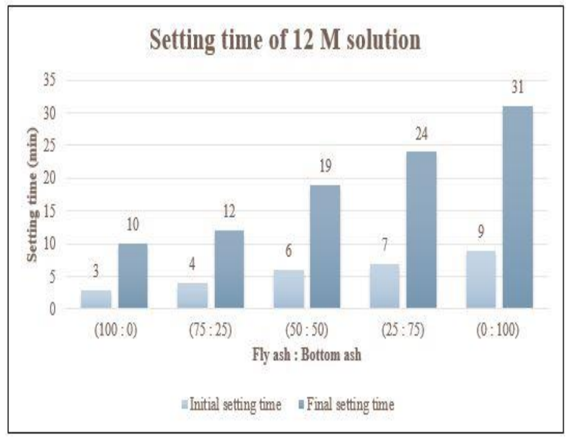
Table 5 : Mix proportioning of alkali activated mortar mixes

Mix Constituents		Proportion				
Fly ash: Bottom ash		100:0	75:25	50:50	25:75	0:100
NaOH (% of source material)	8M	13.9	14.5	17.5	20.8	26.6
	12M	9.5	10.4	11.25	12.1	15.8
Na_2SiO_3 (% of source material)	8M	27.8	29	35	41.6	53.3
	12M	19.2	20.8	22.5	24.2	31.7

Figure 1 : Consistency of alkali activated mortar

Table 5 shows the amount of NaOH and Na_2SiO_3 used for consistency of alkali activated mortar mixes with different proportion of fly ash and bottom ash. 8M and 12M NaOH solution was used in alkaline solution. It was observed that requirement of alkaline solution is increased when amount of bottom ash increases and concentration of NaOH solution decreases. Figure 1 represents the results of the consistency measurements of alkali activated mortar for different combinations of fly ash and bottom ash content. It can be observed that consistency of alkali activated mortar increases with increase in the concentration of NaOH solution. Figures 2 and 3 represent the initial and final setting time for different proportion of fly ash and bottom ash with 8M and 12M NaOH solution, respectively. Increase in the concentration of NaOH solution resulted in reduction in initial and final setting time for all the mixes. Initial and final setting time of alkali activated mortar increased for all the mixes with increase in the amount of bottom ash. Mortar with higher amount of fly ash has fast setting behavior that is inconvenient for the alkali activated concrete in professional construction practices. Therefore, taking into consideration of the above factors, equal dosage of fly ash and bottom ash can be recommended for detailed investigations.





Figures 2 & 3: Setting time of alkali activated mortars (8M solution & 12M solution)

5. COMPRESSIVE STRENGTH RESULTS OF ALKALI ACTIVATED CONCRETE

5.1 Variation in Source Materials

Table 6 : Mix proportioning of alkali activated concrete mixes

Alkali activated concrete mix	Fly ash (kg)	Bottom ash (kg)	Aggregates		Sodium Hydroxide (kg)	Sodium Silicate (kg)	Extra water (kg)	Super-plasticiser (kg)
			10 mm down (kg)	Fine Sand (kg)				
T-1	300	129	1170	630	57.14	114.28	43	4.3
T-2	215	215	1170	630	57.14	114.28	43	4.3
T-3	129	300	1170	630	57.14	114.28	43	4.3
T-4	206	206	1121	604	54.76	109.52	41	4.1
T-5	197	197	1073	576	52.38	104.76	40	4.0

Few alkali activated concrete mixes have been cast based on literature review and studies conducted on alkali activated mortar using varying proportion of fly ash and bottom ash in order to understand the effect of variation in source materials. Ratio of fly ash to bottom ash has been varied of 70:30 (T-1), 50:50 (T-2) and 30:70 (T-3). The amount of source material is varied in the range of 393 kg/m^3 (T-5), 412 kg/m^3 (T-4) and 429 kg/m^3 (T-2). The details of mix proportioning of mixes (T-1 to T-5) are presented in Table 6. Figure 4 represents the compressive strength results of the mentioned alkali activated concrete mixes. It can be seen from the results that compressive strength of concrete increases as the ratio of fly ash to bottom ash by mass is increased. Mix T-1 with 70:30 ratio of fly ash to bottom ash gives the higher compressive strength as compared to that of the mixes T-2 and T-3 as given in Figure 4. Mix T-2 with higher amount of source material gives the higher compressive strength results as compared to that of the mixes T-4 and T-5 as shown in Figure 4.

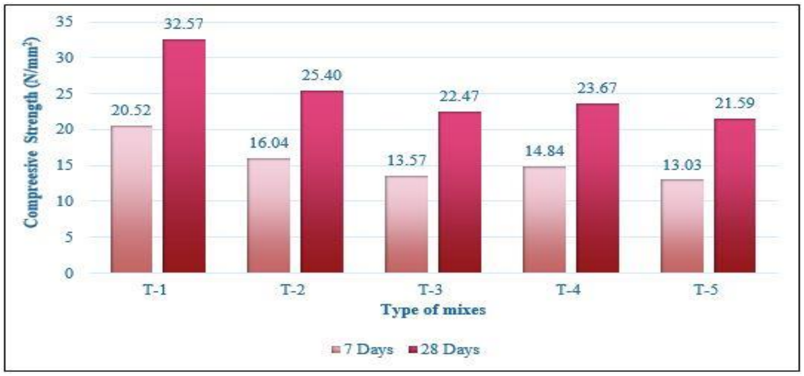


Figure 4 : Compressive strength results of alkali activated concrete mixes

5.2 Variation in Other Salient Parameters

Table 7 : Mix proportioning of alkali activated concrete mixes

Alkali activated concrete mix	Fly ash (kg)	Bottom ash (kg)	Aggregates		Sodium Hydroxide (kg)	Sodium Silicate (kg)	Extra water (kg)	Super-plasticiser (kg)
			10 mm down (kg)	Fine Sand (kg)				
T-6	215	215	1170	630	57.14	114.28	43	4.3
T-7	223	223	1170	630	51.85	103.70	43	4..5
T-8	215	215	1170	630	48.98	122.44	43	4.3
T-9	215	215	1170	630	48.98	122.44	43	4.3
T-10	215	215	1170	630	48.98	122.44	43	4.3
T-11	215	215	1170	630	48.98	122.44	43	4.3
T-12	215	215	1170	630	48.98	122.44	43	4.3
T-13	215	215	1170	630	48.98	122.44	43	0.0
T-14	215	215	1170	630	48.98	122.44	43	0.0
T-15	215	215	1170	630	48.98	122.44	65	0.0

Table 8: Variations in salient parameters of alkali activated concrete mixes

Alkali activated concrete mix	NaOH Molarity	Curing	Rest Period (days)	Alkaline liquid ratio	Super-plasticiser (%)	Extra water content (%)	Alkaline solution to source material ratio	Varying Parameters
T-6	12	Ambient	1	2	1.0	10	0.4	Alkaline solution/source material =
T-7	12	Ambient	1	2	1.0	10	0.35	Alkaline solution/source material =
T-8	12	Ambient	1	2.5	1.0	10	0.4	Alkaline ratio = 2.5
T-9	8	Ambient	1	2.5	1.0	10	0.4	Molarity = 8 M
T-10	10	Ambient	1	2.5	1.0	10	0.4	Molarity = 10 M
T-11	14	Ambient	1	2.5	1.0	10	0.4	Molarity = 14 M
T-12	16	Ambient	1	2.5	1.0	10	0.4	Molarity = 16 M
T-13	14	Ambient	1	2.5	0.0	10	0.4	Superplasticiser = 0.0%
T-14	14	Ambient	2	2.5	0.0	15	0.4	Rest period = 2 day
T-15	14	Ambient	1	2.5	0.0	15	0.4	Water content = 15%

Several alkali activated concrete mixes have been cast based on literature review and studies conducted on alkali activated mortar in order to understand the effect of variation in salient parameters on the compressive strength. These parameters included, alkaline liquid to source material ratio of 0.35 and 0.4; alkaline liquid ratio of 2 and 2.5; concentration of NaOH solution of 8M, 10M, 12M 14M and 16M; addition of super plasticizer of 0% and 1%; extra water content of 10% and 15% and rest period of 1 day and 2 days, respectively. Ambient curing condition has been kept constant through the study. The details of all constituents of alkali activated concrete mixes (T-6 to T-15) are presented in Table 7. Table 8 presents the details of variations employed in salient parameters for alkali activated concrete mixes (T-6 to T-15).

5.2.1 Ratio of Alkaline Solution to Source Material

Mixes T-6 and T-7 have been cast with the alkaline liquid to source material ratio of 0.40 and 0.35, respectively. The effect of variation in the mentioned ratio on compressive strength of alkali activated concrete has been observed at the age of 7 and 28 days as shown in Figure 5. 36.85% increment in compressive strength has been observed for mix T-6 at 28 days as compared to that at 7 days. 51.35% increment in compressive strength for mix T-7 has been observed at 28 days as compared to that at 7 days. 25% and 2.63% higher compressive strength has been observed for mix T-6 as compared to that of mix T-7 at 7 days and 28 days, respectively. Thus, higher compressive strength is achieved with alkaline solution to source material ratio of 0.4. Hence, mix T-6 has been selected for the investigation mentioned in 5.2.2.

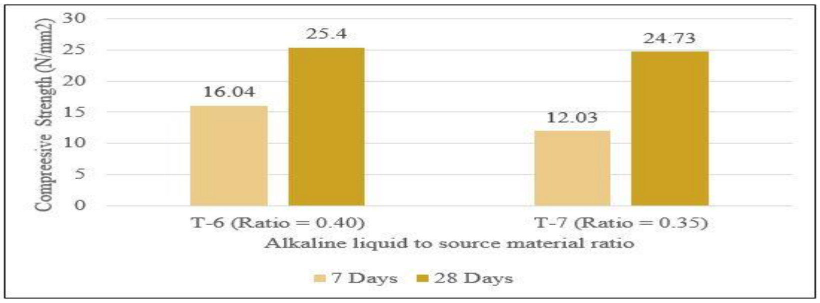


Figure 5 : Effect of alkaline liquid to source material ratio on compressive strength

5.2.2 Ratio of Sodium Silicate to Sodium Hydroxide

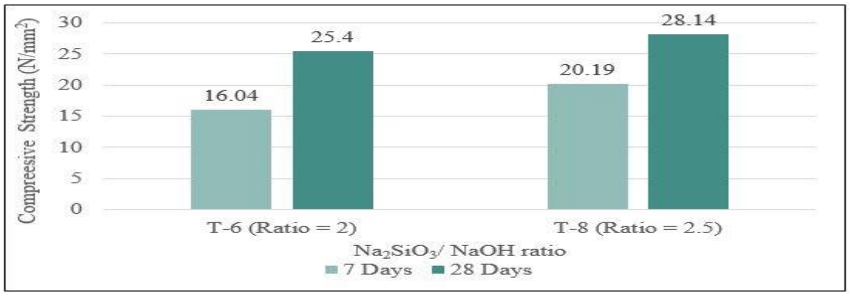


Figure 6: Effect of Na_2SiO_3 to NaOH ratio on Compressive Strength

Mixes T-6 and T-8 have been cast with the sodium silicate to sodium hydroxide ratio of 2 and 2.5, respectively. The effect of ratio of sodium silicate to sodium hydroxide by mass on compressive strength of alkali activated concrete has been observed by comparing results of mixes T-6 and T-8 as shown in Figure 6. 36.85% increment in compressive strength has been observed for mix T-6 at 28 days as compared to that at 7 days.28.25% increment in compressive strength has been observed for mix T-8 at 28 days as compared to that at 7 days. 20.55% and 9.73% higher compressive strength has been observed for mix T-8 as compared to that of mix T-6 at 7 days and 28 days, respectively. Thus, higher compressive strength is achieved with ratio 2.5 as compared to the ratio 2. Hence, mix T-8 has been selected for the investigation mentioned in 5.2.3.

5.2.3 Concentration of Sodium Hydroxide Solution

Mixes T-8 to T-12 have been cast with varying concentration of sodium hydroxide. The compressive strength of mixes T-8 to T-12 at the age of 7 and 28 days has been presented in Figure 7. 66.52% and 60.69% higher compressive strength has been observed for mix T-12 as compared to that of mix T-9 at 7 days and 28 days, respectively. Thus, higher compressive strength is achieved with higher concentration of sodium hydroxide. Mix T-11 has been able to give minimum required strength based on provisions of IS456 [15] and hence it is selected for the investigation mentioned in 5.2.4.

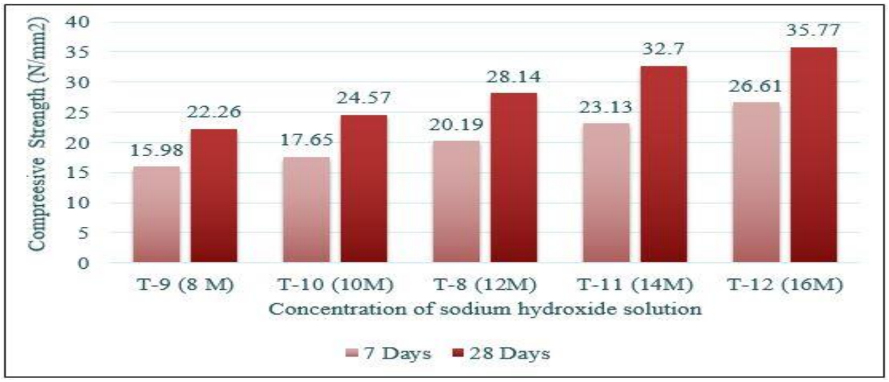


Figure 7: Effect of concentration of NaOH solution on compressive strength

5.2.4 Addition of Superplasticiser

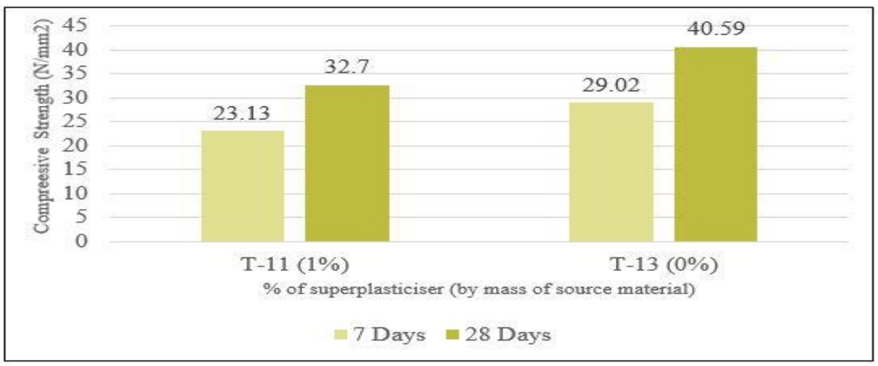


Figure 8 : Effect of Addition of Superplasticiser on Compressive Strength

Mixes T-11 and T-13 have been cast using the superplasticizer dosage of 1% and 0%, respectively. The effect of addition of superplasticizer on the compressive strength of the alkali activated concrete has been observed by comparing results of mixes T-11 with T-13 as shown in Figure 8. 29.26% increment in compressive strength has been observed for mix T-11 at 28 days as compared to that at 7 days. 28.50% increment in compressive strength has been observed for mix T-13 at 28 days as compared to that at 7 days. 20.29% and 19.43% higher compressive strength has been observed for mix T-11 as compared to that of mix T-13 at 7 days and 28 days, respectively. Addition of superplasticizer only helps in achieving good workability of concrete mixes. However, it results into reduction in the compressive strength of the concrete. Therefore, mix T-13 without any superplasticizer has been selected for the investigation mentioned in 5.2.5.

5.2.5 Rest Period Prior to Curing

The term 'Rest Period' is defined by the time taken from the completion of casting of concrete cubes to the start of ambient temperature curing. T-13 and T-14 mixes have been cast with 1-day and 2-days rest period, respectively. The compressive strength results at 7 and 28 days of both mixes are presented in Figure 9.

Mix T-14 with 2-day rest period has resulted into only a minor increment in the compressive strength as compared to that of mix T-13 with 1-day rest period. Therefore, mix T-13 with 1-day rest period has been selected for the investigation mentioned in 5.2.6.

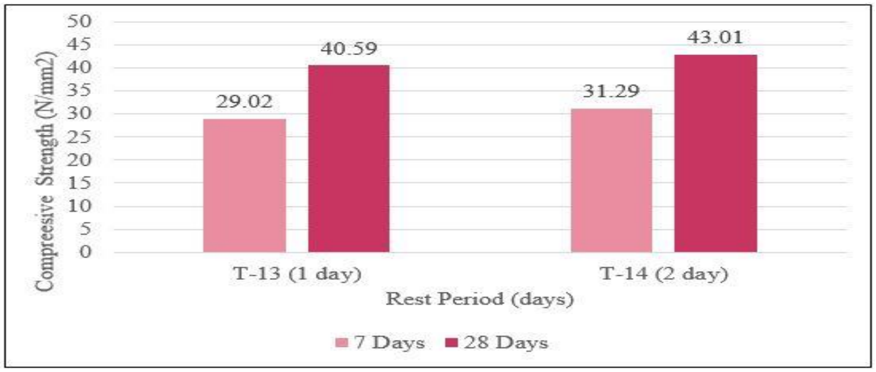


Figure 9: Effect of Rest Period on Compressive Strength

5.2.6 Addition of Water Content to Concrete Mix

Mixes T-13 and T-15 have been cast using 10% and 15% additional water content, respectively. The effect of addition of water content on the compressive strength of the alkali activated concrete has been observed by comparing results of mixes T-13 with T-15 as shown in Figure 10. 28.50% increment in compressive strength has been observed for mix T-13 at 28 days as compared to that at 7 days. 26.08% increment in compressive strength has been observed for mix T-15 at 28 days as compared to that at 7 days. 05.30% and 08.40% higher compressive strength has been observed for mix T-13 as compared to that of mix T-15 at 7 days and 28 days, respectively. Test results indicate that higher compressive strength has been achieved with 10% additional water content as compared to 15% additional water content in the mix.

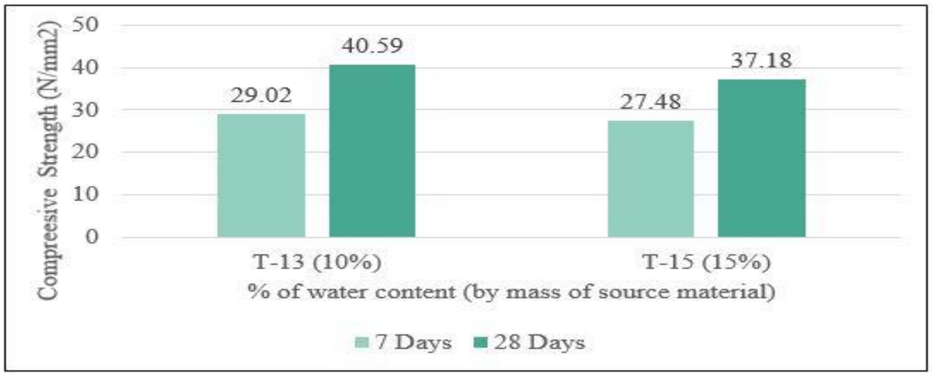


Figure 10 : Effect of Water Content on Compressive Strength

6. CONCLUSIONS

Based on the experimental results presented herewith the following conclusions are drawn:

1. Consistency of alkali activated mortar with different proportion of fly ash and bottom ash increases with increase in the concentration of sodium hydroxide.
2. Increase in the concentration of sodium hydroxide resulted in reduction in initial and final setting time for alkali activated mortar mixes. Initial and final setting time of alkali activated mortar mixes increase as the amount of fly ash reduces and bottom ash increases.
3. Compressive strength of the alkali activated concrete increases as the ratio of fly ash to bottom ash by mass is increased.

4. Higher the ratio of sodium silicate to sodium hydroxide by mass, higher is the compressive strength of the alkali activated concrete.
5. Higher concentration (in terms of molar) of sodium hydroxide results in higher compressive strength of the alkali activated concrete.
6. Minor improvement in the compressive strength of the alkali activated concrete is observed with 2-day rest period as compared to that of 1-day rest period.
7. Compressive strength of the alkali activated concrete decreases with the increase in the additional water content in the mix.

It has been anticipated that the above conclusions would be quite useful for executing the mix design of alkali activated mortar/concrete based on the intended applications in the construction field.

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