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An Exploratory Analysis of Characteristics of Flue Ash and Ground Granulated Blast Furnace Mixed Geopolymer Concrete

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ABSTRACT:

In present days the construction industry needs the replacement of cement with an eco-friendly material, which consumes less energy during its production and less water for curing/hydration purpose. In this connection geopolymer is promising binder which has the ability to replace cement in the construction industry. For the production of geopolymer concrete the base material fly ash which is rich in alumina and silica, is activated with alkaline solutions viz., sodium Hydroxide and Sodium Silicate. An exhaustive review of literature indicated that geopolymer concrete with fly ash as base material can be satisfactorily produced. However, for initial strength gain of geopolymer concrete heat curing for 24 hours at 60ºC is required. This requirement of heat curing discourages the application of geopolymer concrete while concreting at site conditions. Geopolymer concrete is more suitable for precast products as heat curing is an essential requirement. In this connection there is a need for producing geopolymer concrete or Alkali activated concrete which can be cured at the room temperature/ambient temperature. In this direction review of literature revealed that the use of Ground Granulated Blast Furnace Slag (GGBS) along with fly ash is an alternative in producing geopolymer concrete in place of fly ash. This investigation aimed at producing geopolymer concrete that can be cured in the ambient or room temperature only. For accepting this geopolymer concrete in structural applications, various acceptability tests like setting behaviour at green state of concrete and mechanical strength at hardened state of the material. Also a procedure for designing the geopolymer ingredients for a desired strength is a must, so that the field engineers can readily use this material are to be evaluated. The durability aspect of this new material needs to be understood whether this material is suitable for its structural applications.

1. INTRODUCTION

1.1 GEOPOLYMER CONCRETE

The concrete in which locally available industrial by-product materials or geological origin materials are used as a binder instead of cement is known as Geopolymer Concrete. Geopolymer Concrete is economical and eco-friendly as it utilises the abundantly available wastes . In fly ash based geopolymer the silica and alumina present in the source material are induced by alkaline activators to form a gel known as sodium aluminosilicate hydrate gel, which binds aggregates with any unreacted materials to form GPC. In fly ash based GPCs, polymerisation needs temperature, therefore the specimens are cured at 40-70°C for a period of 24 to 48 hours.

1.2 ADVANTAGES AND DIS ADVANTAGES OF GEOPOLYMER CONCRTE

Geopolymer concrete has numerous advantages over conventional concrete. The high early strength gain, good resistance to acid attack, insignificant drying shrinkage, low creep makes GPC a suitable material for infrastructure.The performance of GPC is better than Conventional Concrete under fire exposure. The main advantage of geopolymer technology is its ability to productively utilise large quantity of waste materials. Hence the suitable option for the concrete industry to reach the current CO2 objective would be by shifting to eco-friendly materials like geopolymer concrete.In spite of the many advantages of geopolymer concrete as discussed above, it has some disadvantages that must be rectified before geopolymer concrete can be used widely. The main disadvantage is handling of GPC which needs chemicals for activation which are harmful and should be handled properly. The second problem is the sensitivity of the geopolymerisation process. Many researchers have arrived at conflicting conclusions regarding the factors affecting strength and workability of GPC. Hence further research in the field of geopolymer concrete is needed. Unless such research provides consistent data regarding the properties of GPC and its production, it is not feasible to replace OPC that is being used throughout the world since its development in the 1840's. Although the setbacks of using GPC are compared to its benefits, there is a major problem to its wide applications.

1.3 APPLICATIONS OF GEOPOLYMER CONCRETE

The use of GEOPOLYMER CONCRETE is most advisable in precast applications due to its need for higher temperature curing conditions. In 2004, fly ash based GPC was used in the construction of railway sleepers, sewer mines, structural elements and retrofitting due to its excellent bonding with conventional concrete .Geopolymer concrete is also suitable for the underwater structures where early strength and rapid strength is required. Geopolymer composites were used to strengthen concrete structures such as reinforced beams. Geopolymer concrete can also be used for repair and rehabilitation of distressed structures.

1.4 OBJECTIVES

Existing literatures gives that many researchers carried out works on geopolymer concrete, but a proper mix design wasn't developed till date with both fly ash and GGBS as binders. Hence proper quantification for geopolymer concrete materials is necessary to use with ease for practical applications. FA-based geopolymers need an external energy source in the form of thermal curing for the reaction to take place. The partial replacement of FA with GGBS was found to be beneficial in not only avoiding the need for elevated curing temperatures but also in improving compressive strengths. This work presents the development of GPC under oven and outdoor curing and suggests the attainment of strength under outdoor curing also, with proper proportions of fly ash and GGBS.

2. LITERATURE REVIEW:

1. Rattanasak et al. (2011), carried the experimental investigation on setting times and strength of the high calcium fly ash based geopolymer pastes. Calcium chloride and Sucrose were taken as admixtures by weight of the fly ash as 1% and 2% and concluded that the calcium chloride decreases the initial setting time whereas sucrose delays the final setting time. The dosage of 1% gives the better results compared to 2% as per this study.

2. Kumar et al. (2011), studied the behaviour of fly ash based geopolymer for different parameters such as fly ash to alkaline solution ratio, concentration of sodium hydroxide and sodium silicate and geopolymer solids to water ratio, to find which combination of those parameters yields the maximum compressive strength. It has been found that the optimum contents of parameters are fly ash: alkaline solution as 60:40, concentration of sodium hydroxide as 12M, concentration of sodium silicate as 2M, geopolymer solids to water ratio as 2.15 and sodium silicate to sodium hydroxide ratio as 2.5.

3. Hardjito et al. (2008), studied the setting behaviour of fly ash based geopolymers for different parameters such as concentration of sodium hydroxide, ratio of alkaline solution to fly ash, curing temperature and ratio of water to geopolymer solids. From this experimental investigation, it has been concluded that increase in the concentration of sodium hydroxide increased the compressive strength of geopolymer mortars. The curing temperature also plays an important role in attaining the strength of the geopolymers.

4. Reddy et al. (2010), studied the fresh and hardened properties of low calcium fly ash based geopolymer concrete. The concentrations of the sodium hydroxide taken were 10M, 12M, 14M and 16M, ratio of sodium hydroxide and sodium silicate as 2.5 and oven curing 60°C for 24 hours. From the experimental investigation it has been observed that with an increase in concentration of sodium hydroxide, there was decrease in the workability and increase in the compressive strength of GPC. For every concentration of NaOH, with increase in the age, the compressive strength has improved.

5. Patnkar et al. (2013), investigated the fly ash based geopolymer concrete by varying the water to geopolymer binder ratio (0.16, 0.20, 0.25, 0.30, 0.35 and 0.40). It has been found that with an increase in water to geopolymer binder ratio, the workability of GPC has increased but compressive strength was found to be decreasing similar to that of the conventional concrete.

6. Thokchom et al. (2009), reported the durability characteristics of fly ash based geopolymer mortars by conducting the tests of sorpitvity, water absorption, porosity and compared residual behaviour of geopolymer mortars immersed in sulphuric acid with varying %Na2O (5, 6.5 and 8%) in the activator solution. Higher the %Na2O content, lesser the water absorption, sorpitvity, porosity and better the performance of geopolymer mortar under sulphuric acid attack.

7. Bakri et al. (2011), studied the properties of fly ash based GPC and reported that with the increase in fineness of fly ash, the porosity of geopolymer concrete reduced and hence its compressive strength increased. From the study, it was also concluded that fly ash based GPC showed better performance in aggressive environment and at elevated temperatures than normal concrete.

3. MATERIAL DETAILS

3.1 Fly ash and GGBS

The chemical compositions of GGBS and fly ash were presented in Table 4.1. Fine Aggregate used is clean dry standard sand.

Table 1: Chemical composition of fly ash and GGBS (% by mass)

Chemical Composition	**Fly ash**	**GGBS**
SiO2	60.11	34.06
Al2O3	26.53	20
Fe2O3	4.25	0.8
SO3	0.35	0.9
CaO	4.00	32.6
MgO	1.25	7.89

Na2O	0.22	NIL
LOI	3.25	3.72

4. Test Setup and Testing Procedure

As per IS: 4031-Part-4 (BIS, 1988) normal consistency or standard consistency of cement is determined using the Vicat's apparatus. Similar procedure is adopted for testing geopolymer material and alkaline solution is used to produce geopolymer paste of standard consistency. The standard consistency or the normal consistency of the geopolymer paste is defined as the percentage of alkaline activator which allows the plunger of Vicat's apparatus to penetrate to a depth of 33-35 mm from the top of Vicat's mould.The final setting time of geopolymer paste was determined with help of Vicat's Apparatus taking 400 grams of binder combinations (fly ash and GGBS) and 0.85 times of alkaline activator to produce geopolymer paste of normal consistency (0.85 P).Three cubes of each geopolymer mortar set with dimensions 100mm × 100mm × 100mm are cast and tested in compression to determine 28 days compressive strength.

5. RESULT ANALYSIS

5.1 Normal Consistency

The values of normal consistency for different mixes of binder content were shown in Table

It can be observed that geopolymer paste with 100% fly ash requires less alkaline activator for normal consistency than geopolymer paste with 100% GGBS. In case of intermediate mixes, increase in GGBS content resulted in increased normal consistency value. The reason for this behaviour can be attributed to the fact that fly ash particles are spherical and exhibit less internal friction allowing free movement of Vicat's plunger for lower alkaline activator content. On the other hand, GGBS particles are straight, flaky- elongated shape with sharp-edged angularity, rough surface texture possessing high internal friction compared to fly ash particles, and hence need more alkaline activator to achieve normal consistency. The consistency is found to be 37% with the combination of 70% GGBS and 30% fly ash. With increase in the GGBS content in the different combinations there is an increase the normal consistency. Generally for cement the normal consistency ranges from 28 to 32%. The reason for this increase in the normal consistency of geopolymer paste with that of cement paste is due to the higher viscous nature of alkaline activator solution than that of water. Increase in the GGBS content also effects the normal consistency. For 100% fly ash the normal consistency is found to be 28%. With increase in the GGBS content in the combinations the normal consistency increased from 28 to 33% up to the combination 70% fly ash and 30% GGBS thereafter for other combinations 30% fly ash and 70% GGBS there is no much variation almost constant the normal consistency at 100% GGBS it is 37% is observed. This consistency value indicate that the geopolymer concrete in its green stage would require more alkaline solution from workability aspect also. It can be seen that the molarity of sodium hydroxide in alkaline activator is not influencing the normal consistency of the geopolymer material of a given combination. From this discussion, it can be inferred that proportion of GGBS and fly ash increase the normal consistency of the geopolymer. Increase in concentration of sodium hydroxide does not show any effect on the consistency of the geopolymer paste. The consistency values obtained in these tests are taken for ascertaining the setting time of fly ash and GGBS based geopolymer pastes.

Table 2: Normal consistency of fly ash and GGBS paste for different molarities of NaOH

S. No.	Calcined Source material Combination		Percentage of Alkaline activator required to produce Geopolymer Paste (P)		
	Fly ash (%)	**GGBS (%)**	**8 M**	**12 M**	**16 M**
1	100	0	28	28	27
2	90	10	27	27	28
3	80	20	31	30	31
4	70	30	33	31	32
5	60	40	33	33	32
6	50	50	33	33	33
7	40	60	33	33	35
8	30	70	33	35	38
9	20	80	37	37	39
10	10	90	37	37	39
11	0	100	37	37	39

5.2 Final setting

Setting behaviour of geopolymer is studied by varying sodium hydroxide concentration (8M, 12M and 16M) and by varying the proportions of GGBS in fly ash. Final setting time reported in this study is the final setting time of geopolymer paste of different combinations of fly ash and GGBS. The procedure adopted for determining the final setting time of fly ash and GGBS (Binder) paste is same as the procedure followed for determining the setting time of cement. The variation of final setting time of different mixes of fly ash and GGBS with the variation of molarity of the sodium hydroxide is presented in Table 4. The final setting time of different mixes considered in this investigation varied from 40 minutes to 330 minutes. It is found that increase in the molarity of sodium hydroxide give rise to in increased final setting time. For the mix is 100% fly ash, the final setting time increased from 200 minutes (with alkaline solution having sodium hydroxide of 8 M) to 330 minutes (with alkaline solution having sodium hydroxide of 16 M). When the fly ash content is totally replaced by GGBS, the final setting time increased from 40 minutes (with alkaline solution having sodium hydroxide of 8 M) to 60 minutes (with alkaline solution having sodium hydroxide of 16 M). This behaviour clearly indicates that the GGBS readily reacts with the alkaline activator compared to fly ash. The setting aspects of GGBS with the alkaline activator are faster than fly ash. Thus for developing high early strength geopolymer material GGBS is a better source material than fly ash. Partial replacement of fly ash by GGBS by 20% decreased the final setting time from 200 to 120 minutes when the molarity of the sodium hydroxide is 8M. From the test data it is clear that final setting time has drastically reduced from 200 to 40 minutes when the total fly ash is replaced by GGBS for mix with sodium hydroxide concentration of 8M. The alumina content present in the source material (Fly ash and GGBS) has dominant effect on the setting time of GPC (Silva, 2008). Increase in alumina content decreases the setting time of the matrix. Fast setting behaviour is not convenient for geopolymer mortar in conventional construction. Thus it can be concluded that to have a desired value of final setting time a suitable combination of GGBS and fly ash can be advocated. For the mix of 100% fly ash the normal consistency of the geopolymer paste was found to be is 28% and the alkaline activator used for estimating the final setting time is 0.85P (0.85X28= 23.8%). Whereas for 100% GGBS based geopolymer paste, the normal consistency is 37% and the alkaline activator used for estimating final setting time is 0.85P (0.85X37= 31.45%). The chemical composition difference between GGBS and fly ash and difference in the amount of alkaline activator perhaps decreased setting time for 100% GGBS based geopolymer paste.

Table 3: Final Setting time of geopolymer paste for various molarities of NaOH

S. No .	Calcined Source material Combination		Final Setting Time (minutes)		
	Fly ash (%)	**GGBS (%)**	**8 M**	**12 M**	**16 M**
1	100	0	200	250	330
2	90	10	145	170	250
3	80	20	120	140	185
4	70	30	110	125	148
5	60	40	100	105	120
6	50	50	95	100	115
7	40	60	80	90	100
8	30	70	70	85	95
9	20	80	60	70	80
10	10	90	50	60	70
11	0	100	40	50	60

5.3 Compressive Strength of fly ash and GGBS based Geopolymer Mortar

The compressive strengths of geopolymer mortars having different proportions of fly ash and GGBS along with different concentrations of sodium hydroxide in alkaline activator were shown in Table 4.5, Table 4.6 and Table 4.7. The compressive strength of geopolymer mortar ranges from 41MPa to 87MPa.In outdoor cured samples the compressive strength ranges from 41MPa to 69MPa with variation in molarity of sodium hydroxide. It was observed that with an increase in molarity of sodium hydroxide, there was an increase in the compressive strength of the geopolymer mortar and similar trend was reported by (Hardjito et al. 2004). In case of outdoor cured samples, increase in percentage replacement of fly ash with GGBS increased the strength of geopolymer mortar. With increase in GGBS content the gap between the strengths of outdoor and oven curing showed a very little difference indicating that the use of GGBS along with fly ash will produce high strength even the specimens are cured at outdoor temperature with sodium hydroxide of low molarity. The maximum strength at 100% GGBS is 75 MPa cured under outdoor with low molarity 8M whereas for oven curing the strength is about 82 MPa. For 100% fly ash the strength is about 41 MPa for the same mix coming to 50% fly ash and 50% GGBS the strength is about 50 MPa. Increase in the GGBS content from 0 to 50% the improvement in the strength is about 9MPa. The compressive strength of geopolymer mortar for 100%GGBS content is about 79MPa. This indicates that geopolymer can attain strength even under outdoor curing if GGBS and Fly ash together are used as source material. The reason for increase in compressive strength due to higher calcium content present in GGBS (32.6%). Oven curing results in an increase compressive strength in fly ash based geopolymer mortar of 17% when compared to that of outdoor sample. However, that increase is only 9.3% for a similarly activated geopolymer mortar with 100% GGBS as source material.

Table 4: Compressive strengths of geopolymer mortars with alkaline activator Sodium Hydroxide 8 Molarity

S. No.	Calcined Source Materials		Compressive Strength (N/mm^2) at 28 days	
	Fly ash	**GGBS**	**8M (Outdoor Curing)**	**8M (Oven Curing)**
1	100	0	41	52
2	90	10	44	54
3	80	20	46	55
4	70	30	49	56
5	60	40	50	58
6	50	50	50	59
7	40	60	52	62
8	30	70	57	65
9	20	80	63	72
10	10	90	69	77
11	0	100	75	82

Table 5: Compressive strengths of geopolymer mortar with alkaline activator Sodium Hydroxide 12 Molarity

S. No.	Calcined Source Materials		Compressive Strength (N/mm^2) at 28 days	
	Fly ash	**GGBS**	**12 M (Outdoor Curing)**	**12 M (Oven Curing)**
1	100	0	44	53
2	90	10	45	55
3	80	20	47	57
4	70	30	50	59
5	60	40	52	61
6	50	50	53	65
7	40	60	55	68
8	30	70	62	74
9	20	80	65	77
10	10	90	72	82
11	0	100	78	85

Table 6: 28 day compressive strengths of geopolymer mortars with alkaline activator Sodium hydroxide 16 Molarity

S .No.	Calcined Source Materials		Compressive Strength (N/mm^2) at 28 days	
	Fly ash	**GGBS**	**16 M (Outdoor Curing)**	**16 M (Oven Curing)**
1	100	0	45	54
2	90	10	47	58
3	80	20	52	62
4	70	30	56	63
5	60	40	59	65
6	50	50	63	66
7	40	60	65	69
8	30	70	67	73
9	20	80	69	78
10	10	90	75	83
11	0	100	79	87

6. CONCLUSIONS

1) Molarity of sodium hydroxide in the alkaline activator of geopolymer does not affect normal consistency significantly.
2) Final setting time increases with increase in concentration of sodium hydroxide solution.
3) Replacement of fly ash with GGBS decreases the final setting time of geopolymer paste.
4) Increase in the concentration of sodium hydroxide solution results in the higher compressive strength for all combinations of fly ash and GGBS
5) Compressive strength of geopolymer mortar increases with increase in percentage of GGBS content in the mix.
6) To develop geopolymer concrete under outdoor curing condition, combination of fly ash with GGBS can be a possible solution.
7) Method of curing plays an important role in polymerisation process.

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