Experimental Investigations on Geopolymer Concrete Cured at Ambient Temperature

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Abstract. Initial researches on geopolymer concrete utilized fly ash as a major source of binding material, which required heat curing for hardening. This became a major drawback for the application of this type of concrete in in-situ conditions. The goal of the current study was to develop fly ash-based geopolymers that could cure without the use of high heat. The findings indicate that utilizing furnace slag as a binder, replacing a certain percentage of fly ash can be helpful in ambient curing may be suited for acceptable workability, setting time and compressive strength. The addition of GGBS to Class F fly ash aided in achieving setting times and compressive strengths that were equivalent to conventional Portland cement (OPC).

Keywords: Geopolymer concrete, fly ash, ground granulated blast furnace slag, binder property, concrete property

1 Introduction

The construction industry is the largest user of natural resources. Concrete is the second most commonly utilized building material. And cement serves as a primary binder in it. This leads to the worldwide increase in the production of cement. After China, India is the world's second-largest cement producer[5]. According to the Cement Manufacturers Association, the country's cement output reached 300 million tonnes in 2010 and is anticipated to quadruple to almost 550 million tonnes by 2020. (CMA). Cement manufacturing emits greenhouse gases [1] both directly and indirectly, accounting for 5% to 7% of total world industrial emissions each year. The use of industrial by products as an additive or a replacement of cement in the production of concrete has gained the interest of many researchers as it has been proven to improve the properties of cement as well reduce the carbon footprint of the industries in material production.

By utilizing industrial by products as geopolymers in concrete, it is possible to completely eliminate cement from the mix. [4]. Geopolymer is a specialty substance produced by the chemical interaction of silica and alumina-rich source material with an alkaline solution. Geopolymer is recognized as a greener alternative to normal Portland cement concrete. Since low calcium class F fly ash is easily available and contains a relatively good quantity of silica and alumina, they are extensively utilized as source material for the production of geopolymer

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concrete. The necessity for an increased temperature for curing when using a geopolymer in concrete based on fly ash is one of the most significant challenges. As a result, the goal of the research was to develop geopolymer concrete mixes that could cure without heat or at room temperature. The impact of GGBS substitution, the concentration of alkaline activator, and reactor ratios were investigated.

Ken *et al.* [7], This paper provides a short overview of current research of utilizing many industrial by products in the production of geopolymer concrete. The on the use of industrial by-products as major binder ingredients in geopolymer concrete production. The effects of various factors involved in the production of geopolymer concrete were investigated to a greater extent. Some of the factors taken for the study are the curing regime of the concrete post-production, properties of the materials used for the production and use of activators. The mechanical properties of geopolymer m and aggressive environment exposure on the mechanical properties, physical properties, microstructures, and durability characteristics of geopolymer concrete are thoroughly investigated.

Nath, Sarker,[6] This work's focus is to develop a geopolymer concrete based on fly ash suitable for ambient curing conditions. Instead of utilizing high heat, the quantity of fly ash was replaced by OPC cement in a small amount to speed up the geopolymer concrete setting time. Until testing, the specimens were stored at room temperature (about 23 C and Relative Humidity 65-10%). When OPC was employed as low as five percent of the binder, the setting time was decreased to acceptable levels, and the workability was somewhat diminished. The compressive strength on 3rd day improved slightly while there was a significant change in long-term compressive strength.

2 Materials

The materials mentioned below are used in this research for the production of GPC

A. Fly Ash

The major source of aluminosilicate material in the geopolymer concrete and mortar is Class F fly ash acquired from the Tuticorin thermal power station.

The fly ash has a specific gravity of 2.34.

B.Ground Granulated Blast Furnace Slag (GGBS)

The commercially produced GGBS by JSW cement was added as a replacement for Fly ash. According to the provider, the chemical composition and characteristics of GGBS are as follows.

- Specific gravity- 2.9,
- Fineness - 386 m^2/kg
- Magnesia content – 8.20 %
- Sulphide content – 0.61 %,
- Sulphate as SO_3 – 0.24%
- $CaO + MgO + SiO_2$ - 78.12 %
-

C.Fine Aggregate

As a fine aggregate, natural river sand was employed. As per IS 383-1970[10], the sand lies in zone 2. And its fineness modulus is 2.47%. The characteristics of fine aggregate are listed in Table 1.

Table 1 Fine Aggregate Properties

Properties	Values
Specific gravity	2.59
Loose state bulk density	1550.463 kg/m^3
Rodded state bulk density	1699.945 kg/m^3
Water absorption	3.09%

D. Coarse Aggregate

As a coarse aggregate, crushed granite stones of size 20mm and 10mm were employed. The fineness modulus of the aggregate was found to be 7.268 percent. Table 2 gives other properties of coarse aggregate.

Table 2 Coarse Aggregate Properties

Properties	Result
Specific gravity	2.625
Loose state bulk density	1778.618 kg/m^3
Rodded state bulk density	1907.981 kg/m^3
Water absorption	0.217%

E.Alkaline Activators

The alkaline activator used to activate the fly ash was a mixture of SH/SS solution. Since sodium based activators are less expensive than potassium based activators, they were chosen. The sodium hydroxide utilized was commercial-grade flakes with a purity of 97 percent.

The NaOH solution is created by dissolving the NaOH flakes in water. The concentration of the sodium hydroxide solution is measured by calculating the mass of NaOH solids in the solution. It is termed in a molar, M. For all combinations, the content of SH was kept constant (10 M).

A local commercial manufacture provided sodium silicate solution. The sodium silicate had a SiO_2 to Na_2O mass ratio of 2.7, with 12.4 percent Na_2O, 29.7% SiO_2, and 55.9% water.

3.GPC Mix Design

The average geopolymer concrete density was estimated to be 2400 kg/m3 in earlier research [2,3]. The mass of mixed aggregates was calculated to be 77 percent of the total mass of the concrete mix. This amount is comparable to that utilized in OPC concrete, where it will account for 75 to 80 percent of the total mass of the concrete mix. Water absorption values of fine and coarse aggregate were corrected. Except for mixes A40 and A45, the amount of alkaline liquid in relation to the binder is set at 35 percent. For all mixtures except R1.5 and R2.0, the SS/SH ratio was held at 2.5. For all of the mixes, the molarity of sodium hydroxide is preserved at 10M.

2200 kg/m3[5] was used as the final unit weight for mortar mixture proportions. The overall binder content remained unchanged, accounting for one-third of the entire mix. Alkaline solution content, alkaline solution ratio and slag content were all left unaltered. The pastes for testing setting time for various geopolymer mixes were prepared similar to that of respective mix proposition of concrete or mortar mixtures, the aggregate was alone eliminated. The following Table 3 gives the mix details of the geopolymer mortar mix and Table 4 gives the details of the geopolymer concrete mix. The nine mixes are proportioned based on these values.

Table 3 Geopolymer Mortar Mix Details

Mix no	Mix ID	Sand	Fly ash	GGBS	SS	SH
1	S00	1214.5	730	0	182.5	73
2	S25	1214.5	547.5	182.5	182.5	73
3	S50/ A35/R2.5	1214.5	365	365	182.5	73
4	S75	1214.5	182.5	547.5	182.5	73
5	S100	1214.5	0	730	182.5	73
6	A40	1178	365	365	208.6	83.42
7	A45	1141.5	365	365	234.6	93.9
8	R1.5	1214.5	365	365	153.3	102.2
9	R2.0	1214.5	365	365	170.33	85.17

4. Specimen Preparation

A solution of 10M NaOH was made. The sodium hydroxide solution was always brought to room temperature 24 hours before casting the cubes since the reaction is very exothermic. To achieve appropriate reactivity between the solutions, $NaSiO_3$ solution was added to NaOH solution 3 to 4 hours before casting[8]. Following the preparation of the solution, the mixture is mixed like ordinary concrete and poured into moulds as quickly as feasible because of the short setting times. With a needle vibrator, the mixes in the moulds were compressed. Nine concrete cubes and nine mortar cubes were formed for each of the nine distinct mixes

produced for this project to examine the compressive strengths of each mix at 3, 7, and 28 days. There were a total of 162 specimens cast. The specimens were demoulded after 24 hours, with the exception of S00, which took longer to set and was demoulded after 3 days.
The specimens were kept at ambient temperature upon demoulding till the day of testing.

Table 4 Details Of Geopolymer Concrete Mix

Mix no	**Mix ID**	**CA**	**Sand**	**FA**	**GGBS**	**SS**	**SH**
1	S00	1289	536	409	0	102	41
2	S25	1289	536	306.7	102.2	102	41
3	S50/A35 /R2.5	1289	536	204.5	204.5	102	41
4	S75	1289	536	102.2	306.7	102	41
5	S100	1289	536	0	409	102	41
6	A40	1289	536	204.5	204.5	116.8	46.7
7	A45	1289	536	204.5	204.5	131.4	52.5
8	R1.5	1289	536	204.5	204.5	85.8	57.2
9	R2.0	1289	536	204.5	204.5	95.3	47.6

Label:
All quantities are in kg/m^3
A = alkaline activator %
S = slag %,
R = Na_2SiO_3 to NaOH Ratio
CA = Coarse Aggregate
SS = Sodium Silicate
SH = Sodium Hydroxide.

fig.1 Sodium Hydroxide Flakes

Fig. 2 Sodium Hydroxide Solution

Fig.3 Casted Geopolymer Mortar cubes

Fig. 4 Casted Geopolymer Concrete Cubes

Fig. 1 and Fig.2 shows sodium hydroxide flakes and sodium hydroxide solution, respectively. Fig 3 shows the casted geopolymer mortar cubes kept for curing, and Fig.4 shows the casted geopolymer concrete cubes kept for curing.

5. Result And Discussion

A. GGBS in the Binder Effects

a. Workability of Geopolymer Concrete

The control mix S00 with 0% GGBS showed the highest slump and compaction factor values compared to geopolymer mixtures substituted with 25, 50, 75 and 100 percent GGBS (mix ID 2, 3, 4 and 5 respectively) though all the five mixtures were mixed with the same quantity of activator solution.

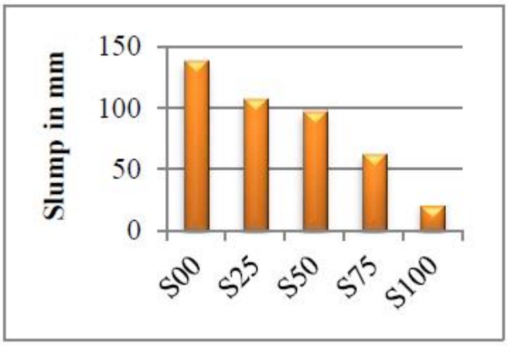

Fig.5 Slag Replacement effects on Slump of Concrete

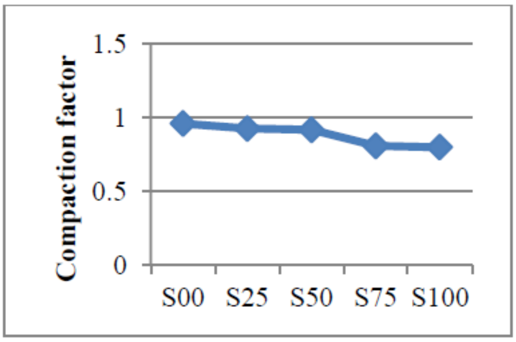

Fig. 6 Effect of Slag Replacement on Compaction Factor of Concrete

The slump and compaction factor values dropped as the slag concentration increased. However, the impact was more pronounced at a greater percentage of slag replacement. Both concrete and mortar mixes follow a similar pattern. The effects of replacement of slag on the slump and compaction factor values of geopolymer concrete mix are plotted in the graph shown in Fig 5 and Fig.6.

b. Setting Time of Geopolymer Paste

It took more than 24 hours for the geopolymer paste with 0% slag component (S00) to show any signs of setting. The setting time of geopolymer pastes was considerably enhanced when slag was added to the solution. With increased slag concentration, both the initial and final setting times were reduced. Mixture 2 with 25% slag had 100 minutes of initial setting time, and it was reduced to 65, 45, and 20 minutes for 50, 75, and 100 percent slag in mixtures 3, 4, and 5, respectively. S00's final setting time could not be established since the beginning setup time was more than 24 hours. The ultimate setting time of combination two was discovered to be 330 minutes, which lowers to 150, 105, and 65 minutes, respectively, when 50 percent, 75 percent, and 100 percent slag is included in mixtures 3, 4, and 5. The large difference in the initial setting time indicates that the pace of the setting grew considerably. The disparity between the initial and ultimate setting times decreased as the slag percentage in the paste increased. The findings show that using slag as part of a binary blended binder can speed up the geopolymer concrete's setting time under ambient conditions.

Fig. 7 shows the results of the initial and final setting time of geopolymer paste due to the inclusion of slag

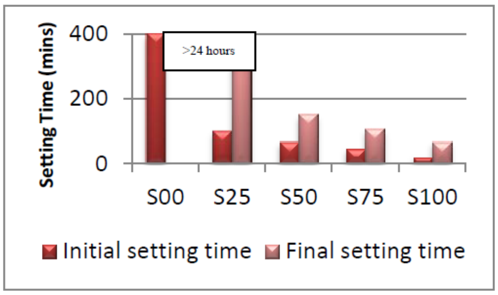

Fig.7 Effect of Slag Replacement on the Setting Time of Geopolymer Paste

c. compressive Strength

When cured in ambient conditions, geopolymer mixtures with only fly ash binder (mix 1) responded slowly to gain strength. From the age of three days, when GGBS was added to concrete mixes, the strength grew significantly. When compared to the control geopolymer combination, concrete mixes containing 25 percent, 50 percent, 75 percent, and 100 percent GGBS of total binder obtained 52.50 percent to 461 percent greater strength after 28 days.

The results of compressive strength for respective slag replacement ratios of geopolymer concrete in Fig.9.

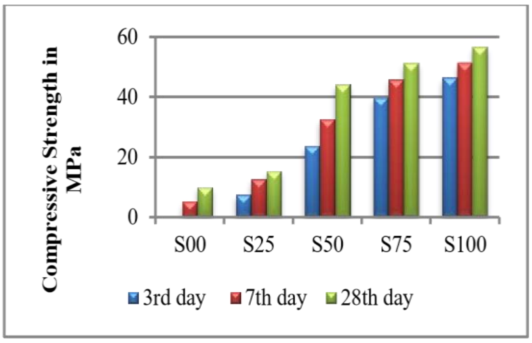

Fig 9: Effect of Slag Replacement on the Compressive Strength of Concrete Cubes

Table 5: Effect Of Slag Replacement On The Compressive Strength Of Mortar Cube

Mix Designation	Average Compressive Strength (MPa)		
	3rd day	7th day	28th day
S00	0	7.544	14.760
S25	11.808	16.073	18.697
S50	30.178	42.643	55.436
S75	44.939	53.140	60.356
S100	51.828	58.060	68.885

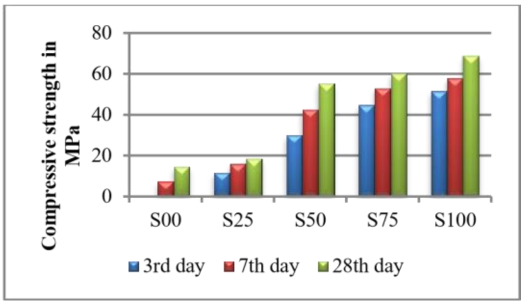

Fig. 9 Effect of Slag Replacement on the Compressive Strength of Mortar Cube

The rise in strength in mortar samples is higher than in concrete samples. After 28 days, mortar mixes with 25 percent to 100 percent GGBS had 26.67 percent to 366 percent greater strength than control geopolymer mixtures. Table 5 shows the results, which are also displayed in Fig 9.

B.Alkaline Liquid Content Effect

a. Workability

The flow of the mixes increased as the activator solution content in the mix increased while all other mix variables were maintained constant (50 percent slag and SS/SH 2.5). A geopolymer mixture containing 35 percent activator liquid (mixture 3) produced a stiff material. In contrast to the combination with 40% liquid (mixture 6), the mixture with 45 percent liquid (mixture 7) created a rather lean mix with high flow.

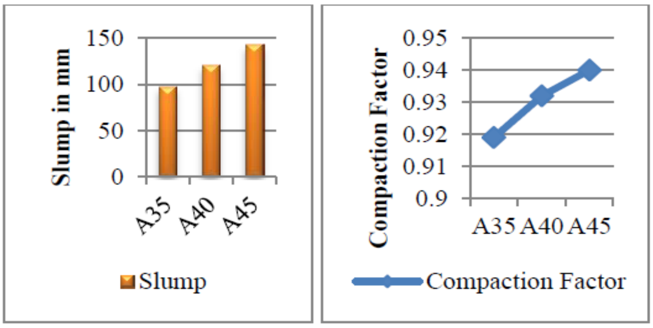

Fig.10 Effect of Alkaline Liquid Content on Workability of Geopolymer Concrete

Fig. 10 shows the results of the slump and compaction factor values of fresh concrete mixtures.

b. Setting Time

The activator to binder ratio has an impact on setting time. As the concentration of the alkaline solution was increased, it took longer for fly ash geopolymer pastes mixed with 50% GGBS to set.

Mixtures containing 35 percent, 40 percent, and 45 percent alkaline liquid had initial setting times of 65 minutes, 150 minutes, and 215 minutes, respectively. With the addition of activator liquid, the final setting time rose as well.

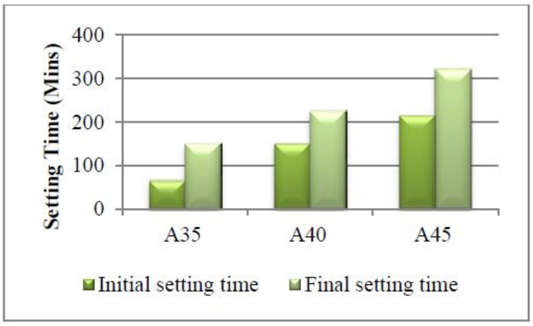

Fig. 11 Alkaline Liquid Content Influence on Setting

Fig.11 shows the value of initial and final setting time for the alkaline content of 35%, 40% and 45%

c. Geopolymer concrete and mortar compressive strength

The compressive strength of the mixes was also impacted by the amount of alkaline activator used. The findings show that gradually rising the activator concentration from 35 percent to 45 percent reduced mortar and concrete strength. When compared to combination 3, the 28-day compressive strength of the concrete samples, which all included 50 percent GGBS, was reduced by 31% and 44% for mix 6 and 7, respectively.

Figure 12 depicts the experimental results of the influence of alkaline liquid concentration on the geopolymer concrete compressive strength.

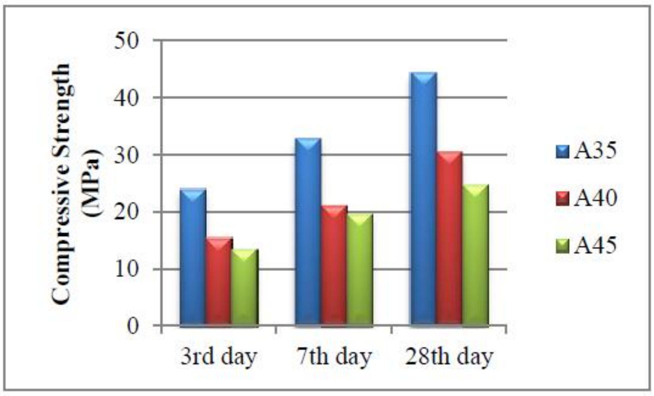

Fig. 12 Effect of Alkaline Liquid Content on Geopolymer Concrete Compressive Strength

The effect was less evident in mortar samples, with 28-day strength dropping 15% for combination 6 and 40% for mixture 7 as compared to mixture 3. In Fig.13, the motor cube's compressive strength on the 3rd, 7th, and 28th days is shown.

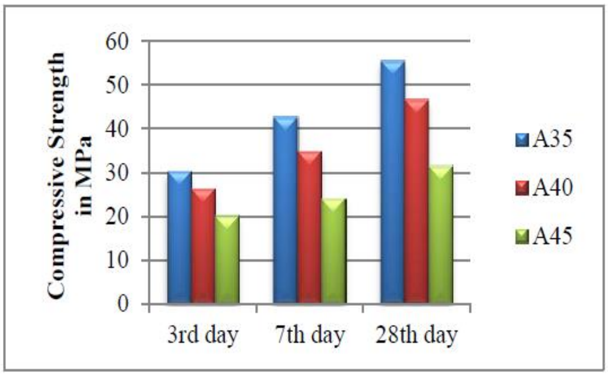

Fig 13 Alkaline Liquid Content effect on Compressive Strength of Geopolymer Mortar

C.ALKALI ACTIVATOR RATIO EFFECT (R)

To change the chemical composition of the activator solution, the ratio of Na_2SiO_3 to NaOH (R) was changed in the mixes 3 (2.5), 8 (1.5), and 9 (2.0).

a. Workability

With an increase in sodium silicate concentration, the compaction factor of concrete and the slump value of mixes decline. However, the slump value of all the mixes were more than 90, the variance in workability is not substantial. The increased mixture's viscosity, which contains a higher amount of Na_2SiO_3, results in a small reduction in a slump. The impact of the alkaline activator ratio on concrete workability is seen in Figure 14.

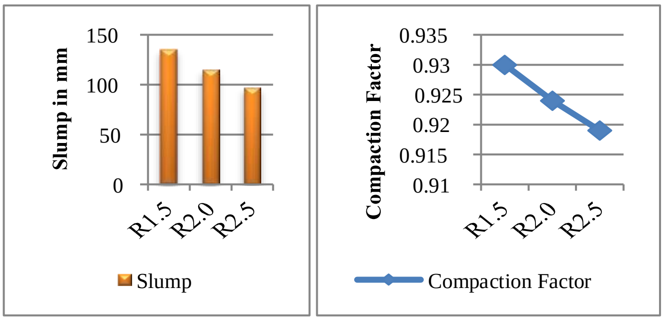

Fig. 14 Effect of Alkaline Activator Ratio on Workability of Geopolymer concrete

b. Setting Time

Setting time was reduced to some extent by increasing the Na_2SiO_3 to NaOH ratio in the alkaline solution and leaving other mix variables unchanged. The least amount of sodium silicate (1.5) in Mixture 8 took longer to set than those with a larger amount of sodium silicate (mixture 9 and mixture 3). Figure 15 depicts the change in setting time caused by the alkaline activator ratio.

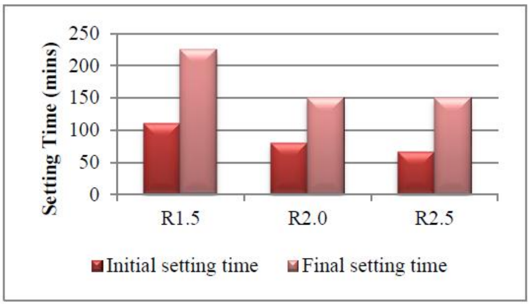

Fig. 15 Effect of Alkaline Activator Ratio on Setting Time of Geopolymer Paste

b. Geopolymer concrete and mortar compressive strength

The geopolymer concrete mixes' 28-day compressive strength did not change appreciably when the ratio R changed. Figures 14 and 15 show the findings of the 3rd, 7th, and 28th day compressive strength of geopolymer mortar and concrete, respectively.

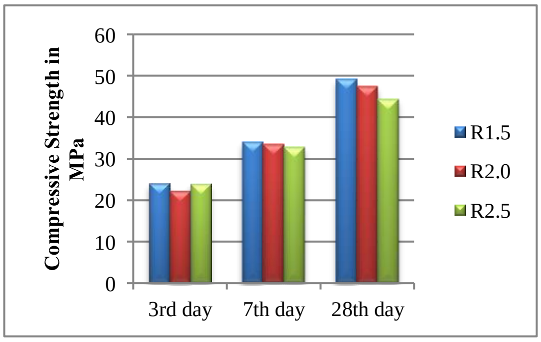

Fig. 16 Effect of Alkaline Activator Ratio on Compressive Strength of Geopolymer Concrete

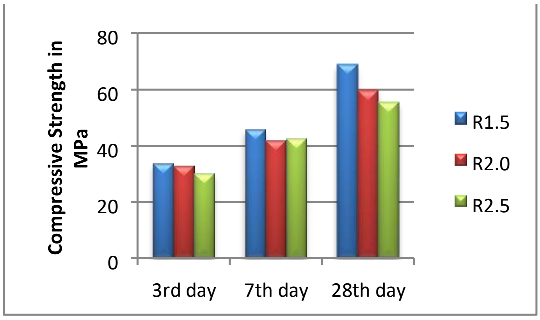

Fig 17 Effect of Alkaline Activator Ratio on Compressive Strength of Geopolymer Mortar

6. Conclusions

The following is a summary of the outcomes of the experimental work:

- The workability and setting time of a fly ash-based geopolymer combination is reduced when the GGBS content is increased.
- With the addition of slag, the concrete slump and compaction factor were reduced.
- When the alkaline liquid concentration was increased, the setting time and workability improved, but the compressive strength decreased.
- Mixtures with a SS/SH of 2.5 had low setting time and workability than mixtures with an activator ratio of 1.5 and 2.0.
- At 28 days, increasing slag content up to 50% of the total binder increased the compressive strength of concrete to 44.327 MPa and the compressive strength of mortar to 55.436 MPa.
- For the increase in overall binder ratio from 35% to 45%, the compressive strength of the mixes decreased.
- The Na_2O/SiO_2 molar ratio was reduced when the activator ratio was changed from 1.5 to 2.5, resulting in a small loss in strength over time.

Finally, it was found that a geopolymer with fly ash and GGBS can serve as a good binder under ambient curing conditions for the production of concrete with moderate strength. The hardship of heat curing is also eliminated. To accomplish the necessary setting time and compressive strength, the proportioning of a fly ash based geopolymer utilizing GGBS as a blend requires an optimal balance in the quantity of slag content, activator content, and activator ratio. A good combination of 50% slag, 40% alkaline activator, and 1.5–2.5 of reactor ratio without additional water can produce concrete for domestic usage with moderate compressive strength under ambient curing conditions.

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