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Variation of sodium hydroxide concentration impact on rheological properties of geopolymer paste

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ABSTRACT

This study focuses on novel technologies that provide breakthrough CO_2 capture and performance. This research aims to identify the usual consistency and to set the time of geopolymer paste to ensure that cement may be substituted with calcined materials. However, it is necessary first to investigate the properties of geopolymer paste, including varied proportions of calcined materials and sodium hydroxide concentrations. According to the published studies, there is a shortage of studies on the entire replacement of fly ash with GGBS (0-100%) with varying concentrations of sodium hydroxide (8M-12M) with an SS/SH ratio of 2.5. Thus, this work might be unique. Moreover, this research work would stand as a benchmark for future researchers in this area. Thus, 198 specimens were prepared to determine the geopolymer paste's normal consistency and setting behavior. The experimental results showed that increasing the amount of GGBS to geopolymer paste reduces the setting time of the paste and raises the standard consistency value for intermediate mixes compared to fly ash combinations. The key finding of this investigation is that an increase in sodium hydroxide concentration does not affect the normal consistency. As a result, the consistency is determined to be 37 percent when using a combination of 80 percent GGBS and 20 percent fly ash is shown to be the most effective in achieving higher performance.

1. Introduction

Conventional concrete is a building material of fine concrete, coarse aggregate, water, and cement. Cement manufacture, on the other hand, releases a substantial quantity of carbon dioxide, which contributes to the greenhouse effect, climate change (about 8% of the globe), and ozone layer depletion, a major issue in most developing nations throughout the world said by Lehne and Preston (2018). Therefore, it is essential to eradicate cement production with locally available industry by-products. Poloju and Srinivasu (2021) utilized waste materials from industries such as fly ash, metakaolin, GGBS, etc. Al-Ruqaishi et al. (2019) studied marble powder and ceramic powder characteristics of concrete. However, Poloju et al. (2017a) explained the use of ceramic powder derived from ceramic tiles with a high quantity of Ca and higher properties than concrete. Generally, concrete is more substantial in compression and weaker in the tension zone. Therefore, Poloju et al. (2018a) suggested that the fibers should be added to the concrete to build more strength and Poloju et al. (2018b) stated that concrete should resist different temperatures. However, the properties of aggregate texture play a significant role in developing the strength properties of concrete, as discussed by Poloju et al. (2017b). Moreover, the properties of aggregate play a vital role in achieving the strength of conventional and geopolymer concrete. Currently, the construction industry demands that cement production be eliminated using industrial by-products that produce fewer emissions into the atmosphere. Hence, geopolymer is an ideal binder capable of substituting cement in concrete preparation. Silica and Alumina are rich source materials mixed with an alkaline activator. The literature review determined that fly ash can be used successfully as a base material for GPC. Nevertheless, geopolymer concrete requires 24 hours of curing at 60°C to gain initial strength. Using geopolymer concrete on a construction site can be difficult because of the heat-curing requirement. In precast

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applications, heat curing is essential, so GPC is an ideal choice. All structures require higher durability, which can be achieved with GPC. The most frequent industrial by-products utilized in the manufacture of GPC are GGBS and Fly Ash. Geopolymer concrete is an environmentally friendly material, as stated by Duxson et al. (2007). In 1978, Davidovits (1984) invented the term "geopolymer" to characterize a group of mineral binders with chemical compositions comparable to zeolite (Davidovits et al., 1990). The alkaline solutions activate the silica and Alumina in geopolymer to form a gel that gives GPC its strength. Geopolymers are cementitious materials with numerous applications in civil infrastructure. Alkaline activators form sodium aluminosilicate hydrate gel, stabilizing the aggregates and any materials not yet reacted with, forming the geopolymer discussed by Wallah et al. (2005). GPCs made from fly ash require high temperatures for polymerization, so the specimens are typically cured for 24 to 48 hours at a temperature of there is much research being conducted in the field of geopolymer concrete, a slag with alkaline activation was probably the first investigated by Purdon (1940) that alkali-activated Many researchers then studied alkali-activated slag substitute for Ordinary Portland Cement (OPC). High calcium fly ash is used to determine the strength of geopolymer have been carried out by Rattanasak et al. (2011), adding the calcium chloride at 1% and sucrose at 2% by weight of fly ash, and it is concluded that the initial setting time reduced by adding calcium chloride and final setting time delayed with sucrose. According to this study, 1% gives better results than 2%. An experiment with fly ash-based geopolymers was conducted by Morsy et al. (2014). Infuse sodium silicate into sodium hydroxide (0, 1, 1.5, 2, and 2.5) at 80 degrees Celsius for 24 hours. Because of its homogenous and less porous matrix has achieved maximum compressive strength at a sodium silicate ratio of 1. According to the study, strength increases with age. The effect of alkaline activator composition with fly ash and GGBS was studied by Deb et al. (2014); geopolymer mortars are tested for their strength by varying the Na_2O content (6 and 8%), the silicate modulus (0, 1, and 1.5), and the curing temperatures (55, 65, 75, and 85 degrees Celsius). For samples based on fly ash, Na_2O content should be higher than in the case of GGBS. Mallikarjuna Rao and Gunneswara Rao (2015) studied different molarities from 8M to 16M, with strength ratios of 1, 2, 3, and 4 under oven temperatures of 30°C, 60°C, and 90°C were investigated to determine their normal consistency and setting times. Alkaline liquid ratios of 1.5 and 2 (between 8 M and 12 M) showed increased sodium hydroxide concentration with increasing setting time. As the sodium hydroxide concentration was increased, the setting time was reduced. Additionally, the temperature had a direct impact on the setting time. In response to the increased temperature, the setting time was significantly shortened. Mallikarjuna Rao and Gunneswara Rao (2015) studied in their laboratory experiments using different molarities (8M, 12M, and 16M) under ambient and heated curing at 60C for 24 hours. Due to the addition of GGBS, the setting time could be reduced, and oven curing could be eliminated. It is also possible to achieve the strength required by only curing outdoors. As reported, the molar ratio of Na2SiO3/NaOH influences the properties of geopolymers. Research shows that max compressive strength can be achieved with a ratio of 2.5 and a constant binder content (Pinto, 2004). Based on Bakharev et al. (1999, 2001) and Bakharev's (2000) investigations, it was found that pre-curing fly ash-based GPC for an extended period at room temperature enhanced strength development. As compared to sodium silicate-activated geopolymers, NaOH-activated geopolymers showed greater ultimate strength. Further, Bakharev (2005) investigated the effect of fly ash on GGBS percentage and alkaline content (altering sodium silicate to sodium hydroxide ratios from 1–1.5) while keeping sodium hydroxide concentration at 10 M. The compressive strength increased as the geopolymer concrete's GGBS and alkaline content increased. The molarity effect on GPC varies in strength. According to Parthiban et al. (2013) studies, the variation of NaOH, strength ratio, and oven curing influence the characteristics of GPC. Regarding maximum compressive strength, the alkaline binder ratio of 2, with 12M, and the strength ratio of 2.5, under a curing temperature of 60 degrees for 24 hours. Al Bakri et al. (2012) changed the concentration of NaOH solution with 3M, 5M, and 7M along with a variation of GGBS content (100%, 75%, and 50%) in fly ash. The results showed that increased concentrations of sodium hydroxide solution led to a higher compressive strength. At 28 days of age, GPC exhibited the maximum compressive strength of 60 MPa with a maximum concentration of Sodium Hydroxide (7M). The temperature significantly impacts the polymerization of geopolymer concrete, as proposed by Madheswaran et al. 2013. Curing at higher temperatures (60°C to 90°C) produces more strength gain. Furthermore, the effect of workability discussed by Chindaprasirt et al. (2007) evaluated the properties of fresh and hardened geopolymer concrete containing fly ash. It was determined that the sodium hydroxide concentrations were 10, 12M, 14M, and 1. The ratio of sodium hydroxide to sodium silicate was 2.5 with an oven curing time of 24 hours at 60°C. GPC shows a decrease in workability and a rise in compressive strength with an increase in sodium hydroxide concentration, based on the results of the experimental study. As age increases, the compressive strength of every concentration of NaOH also improves. The setting behavior of fly ash-based geopolymers was studied by Varaprasad et al. (2010) using different variables, including sodium hydroxide concentration, strength ratio, and different methods. According to the results of this experiment, increasing sodium hydroxide concentration led to a higher compressive strength. A geopolymer's strength is also determined by its curing temperature. From the available literature studies on geopolymers with different molarity, curing conditions, and GGBS content, it is evident that the geopolymer is an excellent binder in concrete, exhibiting good strength, greater durability, economics, and sustainability. However, the properties of geopolymer mortar were observed in this study. Geopolymer Mortar can be prepared more efficiently using sodium oxide and silicate than other alkaline solutions. The compressive strength increases with the dissolution of silicon and aluminum, and the concentration of sodium hydroxide increases. The sodium silicate is obtained as a 2.5 solution in the solution of sodium hydroxide.

1.1. Significance of the project

Geopolymer is a moderately new material, with the possibility to be another option for OPC. The geopolymer has a lower natural effect, bringing about around 85% less CO_2 underway when compared to OPC. The source materials used to produce GPC are obtained from the industry by-products such as fly ash and GGBS with sodium hydroxide and sodium silicate as an alkaline solution. One of the vital CO_2 sources and the essential vitality utilization in the creation of GPC comes about because of the generation of Sodium Silicate and Sodium Hydroxide. The present procedure for producing geopolymer mortar utilizes fly ash and GGBS as the source materials with different molarities to examine the characteristics of geopolymer mortar. A far-reaching appraisal of concrete properties ought to be assessed for influencing the geopolymer with concrete as an auxiliary concrete. The energy required for production could be considerably minimized by using industrial waste. This shows an impact on crude material expenses and, in addition, ozone-harming substance outflows. Furthermore, geopolymer is cost-effective and has excellent strength and thermal resistance.

2. Materials and methods

This research aims to determine geopolymer paste's consistency and behavior with fly ash and GGBS. GGBS is partially substituted for the class F fly ash and activated with an alkaline solution in the mix. In addition to 8, 10, and 12, sodium hydroxide has different molarities (concentrations) and has been used in this investigation.

2.1. Normal consistency

A total number of 99 samples has been prepared with 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% replacement of GGBS in fly ash for 8M, 10M, and 12M to determine the normal consistency of source material. The detailed methodology is shown in Fig. 1.

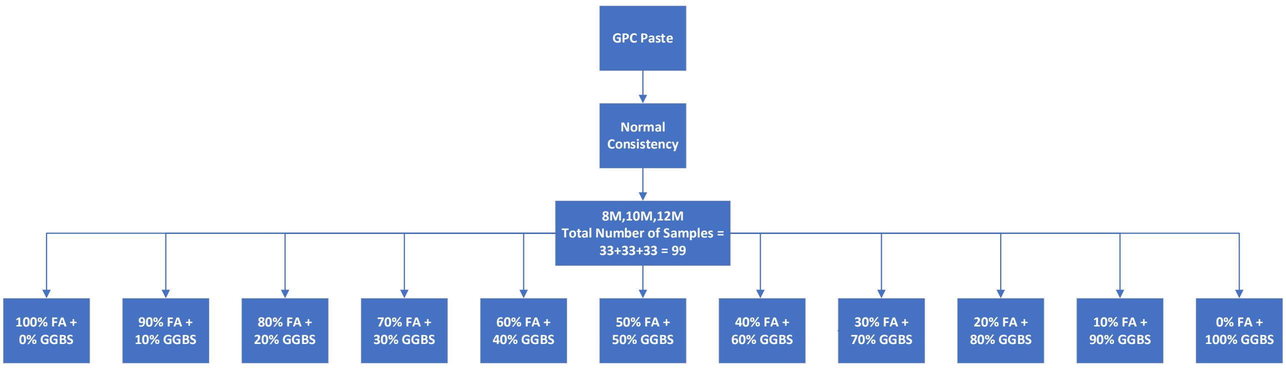

Fig. 1: Various proportions of source material used for final setting time

2.2. Final setting time

A total number of 99 samples has been prepared with 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% replacement of GGBS in fly ash for 8M, 10M, and 12M to determine the setting behavior of source material. The detailed methodology is shown in Fig. 2.

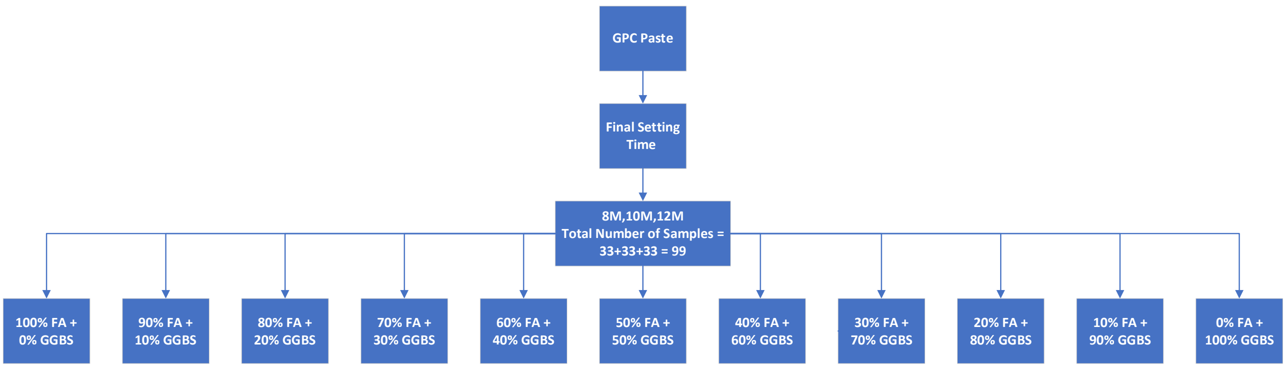

Fig. 2: Various proportions of source material used for final setting time

2.3. Materials used in the investigation

2.3.1. Fly ash and GGBS

Class F fly ash and GGBS with specific gravities of 2.85 and 2.10, respectively, are considered in this research investigation. The chemical composition of the source material is shown in Table 1.

Table 1: Chemical composition of source material (% by mass)

Chemical composition	Fly ash	GGBS
Si O_2	60.10	34.00
Al_2 O_3	26.50	20.00
Fe_2 O_3	4.25	0.8
SO_3	0.35	0.9
Cao	4.00	32.5
MgO	1.25	7.89
Na_2O	0.22	Nil

2.3.2. Alkaline activator solution

The produced solution contains sodium hydroxide and sodium silicate. Sodium hydroxide is chosen in this investigation due to its inexpensive cost and widespread availability. The sodium hydroxide pellets utilized in the study were 98 percent pure. Dissolving these sodium hydroxide pellets in potable water yielded a solution of the requisite molarity. It is combined with the requisite molarity sodium hydroxide solution and kept at the proper temperature for 24 hours before use. Alkaline solutions are made by varying the concentrations of sodium hydroxide at 8, 10, and 12 M. At 8M, for example, 320 grams of NaOH pellets are placed in a 1-liter jar (the atomic weight of sodium hydroxide is 40), and well mixed with water to make the solution. After that, the mixture is weighed. Finally, an alkaline activator is made by adding an appropriate amount of sodium silicate solution (2.5 times the weight of sodium hydroxide solution) studied by Poloju et al. (2020a, 2020b) and Rao et al. (2020).

2.4. Preparation of geopolymer paste

Materials mixed in the dry condition in pan mixers, such as fly ash and GGBS, in varying proportions as shown in Fig. 3. Mix the mixture with the alkaline solution for three minutes to achieve homogeneity. Different ratios of source material were used to prepare a range of geopolymer pastes, each with varying concentrations of alkaline activator (sodium hydroxide).

3. Results and discussion

3.1. Normal consistency of geopolymer past

Table 2, Table 3, and Table 4 summarize the values of normal consistency for various replacement levels of the source material. The results show an increase in normal consistency values for a few mixes with an increase in GGBS content. Because it is evident from the images observed from SEM, the GGBS particles are a sharp and flaky-elongated shape that leads to much higher internal friction than fly ash particles. Therefore, they need a highly alkaline solution to achieve the desired normal consistency. Similarly, it is noticed that 100% fly ash requires a less alkaline activator to achieve the same consistency of 28% as that made with 100% GGBS since fly ash particles need less solution. In addition, the normal consistency increases with increasing GGBS content discussed (Poloju and Srinivasu, 2022). In the case of 70% fly ash and 30% GGBS, it is found that the normal consistency rose from 28 to 33% (Cement usually has a consistency between 28 and 32%). The alkaline solution has a much higher viscosity than water, making it different from cement paste. Geopolymer concrete cannot be used in its green state without an alkaline solution. Moreover, the increase in sodium hydroxide amount does not affect the consistency. Accordingly, increasing GGBS results in increased normal consistency.

Fig. 3: Preparation of geopolymer paste to determine normal consistency

Table 2: Results of normal consistency with 8M

Binder material		The concentration of Sodium Hydroxide
Fly ash	GGBS	8M
100	0	28
90	10	27
80	20	31
70	30	33
60	40	33
50	50	33
40	60	33
30	70	33
20	80	37
10	90	37
0	100	37

Table 3: Results of normal consistency with 10M

Binder material		The concentration of Sodium Hydroxide
Fly ash	GGBS	10M
100	0	28
90	10	27
80	20	30
70	30	31
60	40	33
50	50	33
40	60	33
30	70	35
20	80	37
10	90	37
0	100	37

Table 4: Results of normal consistency with 12M

Binder material		The concentration of Sodium Hydroxide
Fly ash	GGBS	12M
100	0	27
90	10	28
80	20	31
70	30	32
60	40	32
50	50	33
40	60	35
30	70	38
20	80	39
10	90	39
0	100	39

3.1.1. Discussion on consistency

The fly ash-containing geopolymer paste required less alkaline content to obtain better consistency than the GGBS-containing paste. Increasing the GGBS content in intermediate mixes increased standard consistency. Fly ash exhibits less internal friction thanks to its spherical shape, so Vicat's plunger functions with a lower alkaline activator content. Because GGBS particles have elongated, straight, flaky, and sharp angular surfaces, they have a higher level of internal friction than fly ash particles, which require a high amount of solution to achieve better consistency. When combined with fly ash at 80%, GGBS has a consistency of 37%.

3.2. Final setting time

Variations in sodium hydroxide concentration (8M, 10M, and 12M) and GGBS proportions in fly ash were used to assess the setting behavior of geopolymer are shown in Table 5, Table 6, and Table 7. These results refer to the final setting times of the geopolymer pastes made up of various combinations of fly ash and GGBS. It is the same procedure used to determine the set time of fly ash and GGBS paste (Binder) as it is to determine the set time of cement. As the molarity of sodium hydroxide varies with the mix of fly ash and GGBS, the final setting time of the mix changes. Wan et al. (2004) found that the alumina content (Fly ash and GGBS) had a significant effect on the setting time of GPC. As alumina content increases, the setting time of the mix decreases. Thus, GGBS combined with fly ash can be suggested for achieving the desired setting time. The normal consistency of 28% with 100% fly ash, which is used to estimate setting time, is 0.85P (0.85 x 28=23.8%). Likewise, the alkaline activator used to calculate the setting time behavior of 100% GGBS-based paste is 0.85P (0.85*37=31.45%).

3.2.1. Discussion on setting time behavior

Fly ash's reactive process is slower than GGBS, indicating that it is a more reactive compound. Because of its low reactivity, fly ash is slow to set and develop strength. Fly ash often does not dissolve entirely before hardening is studied (Memon et al., 2013). During alkali activation of ash/slag blends, Mullite in fly ash remains unreacted, and calcium appears active. GGBS is faster at setting when used with an alkaline activator than fly ash. Therefore, GGBS is a better source of raw material for geopolymer materials with high early strength than fly ash. When GGBS is replaced by 20%, the setting time decreases to 125 minutes from 200 minutes (for 8M sodium hydroxide). According to the test results, the final setting time has significantly reduced for the 8M mix when GGBS is used instead of total fly ash. Because of geopolymers' quick setting time, they cannot be used in conventional construction. Therefore, GGBS and fly ash are suitable for achieving better setting behavior.

Table 5: Results of final setting time of paste with 8m

Source material		The concentration of Sodium Hydroxide
Fly ash	GGBS	8M
100	0	180
90	10	170
80	20	165
70	30	150
60	40	120
50	50	90
40	60	80
30	70	70
20	80	55
10	90	42
0	100	40

Table 6: Results of final setting time of paste with 10m

Source material		The concentration of Sodium Hydroxide
Fly ash	GGBS	10M
100	0	200
90	10	185
80	20	175
70	30	155
60	40	130
50	50	105
40	60	85
30	70	76
20	80	60
10	90	48
0	100	42

Table 7: Results of final setting time of paste with 12m

Source material		The concentration of Sodium Hydroxide
Fly ash	GGBS	12M
100	0	220
90	10	190
80	20	180
70	30	170
60	40	125
50	50	100
40	60	90
30	70	90
20	80	70
10	90	60
0	100	50

4. Conclusion

The standard consistency is not affected by the sodium hydroxide concentration, where the curing type plays an essential role in polymerization. Due to fly ash's spherical shape, the Vicat plunger requires a less alkaline activator due to less friction internal to the material. GGBS has a consistency of 37% when combined with fly ash at 80%. The setting speed of GGBS is faster than that of fly ash when used with an alkaline activator. Fly ash can be replaced with GGBS to reduce the setting time of geopolymer paste. Otherwise, they could not be used to construct their fast-setting time.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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