Physical and Mechanical Properties of Calcinated Materials under Various Curing Conditions

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Article Info
Page Number: 1443-1458
Publication Issue:
Vol. 71 No. 3s (2022)

Article History
Article Received: 22 April 2022
Revised: 10 May 2022
Accepted: 15 June 2022
Publication: 19 July 2022

Abstract— This article aims to demonstrate that cement may be substituted with calcined materials and to determine the rheological properties of calcined materials utilized in developing a geopolymer mortar, such as normal consistency, setting time, and compressive strength. The new technology may determine conventionally or geopolymer cement's physical and mechanical characteristics. First, however, studies on the total replacement of fly ash with GGBS (0–100%) with various concentrations of sodium hydroxide (8M and 10M) with a Sodium Silicate/Sodium Hydroxide (SS/SH) ratio of 2.5. This research would also serve as a model for future researchers in this sector. As a result, the features of geopolymer paste and mortar to cement were examined in this study under various curing techniques. The results of the tests showed that adding additional GGBS to geopolymer paste reduces the setting time of the paste and raises the standard consistency value for intermediate mixes when compared to fly ash mixtures. The study's key conclusion was that increasing the sodium hydroxide concentration improved the properties of the mortar when compared to ordinary cement mortar. As a result, the maximal strength for 10M under oven and outdoor curing is greater than that of any other mix.

Index Terms— Concentration of sodium hydroxide, Curing methods, Normal consistency, Compressive strength, Calcined materials, Geopolymer mortar, Material characterization

I. INTRODUCTION

Joseph Davidovits invented geopolymer in 1970 to detect waste compounds created by alkaline activation of silica and alumina. Thermal power stations generate a large amount of fly ash, which is utilized in the concrete and brick industries. On the other hand, the disposal of residual fly ash remains difficult. GGBS is a byproduct of blast furnace steel making as well. By replacing cement with fly ash and GGBS, geopolymer concrete reduces carbon dioxide (CO_2) emissions from cement manufacturing and waste management. As a result, it is an environmentally friendly material that helps protect the environment. GPC consists of loose particles that combine with geopolymer to make a material with high strength, high acid resistance, and low creep. Throughout the polymerization process, the curing state of GPC has a significant influence on its strength. Polymerization and stability are improved by curing at temperatures ranging from 60 °C to 90 °C. On the other hand, curing at room temperature produces a modest rise in strength and GPC setting. However, this study examines many concerns because geopolymer mortar is a novel material. A comparison with regular cement mortar is undertaken to allow GPC to be utilized in various applications. According to Palomo et al. [1], the alkaline liquid used in the polymerization process is critical. According to the author of [2,], adding (Sodium Silicate) Na_2Sio_2 to the alkaline liquid, Sodium Hydroxide (NaOH), increased the contact between the source materials. Because of the production of calcium-aluminate-hydrate and other calcium compounds, the author of [3] observed that fly ash with higher calcium oxide (CaO) content produced a higher compressive strength, especially in the early years. Similarly, the authors of [4] supplied the sole information available on the quantitative measurement of geopolymer material setting time using the Vicat's needle up to this point. On the other hand, the author of [5] examined the strength and set times of a geopolymer cement based on low calcium fly ash. According to the findings, the compressive strength of geopolymer mortar rises as the concentration of alkaline activator increases. After 28 days, specimens treated for one day at 65°C had the greatest compressive strength. The authors of [5] and [6] investigated compressive strength growth in ambient cured geopolymer mortar employing marginal materials or industrial wastes for sustainable development. Sahana. R observed that using GGBS in the mortar at less than 40% replacement levels enhances setting time. However, if this level is reached, the setup time decreases, potentially resulting in a loss of workability. The author of [7] demonstrated that workability deteriorated with increasing GGBS concentration due to calcium's fast reactivity and the angular structure of GGBS, as did the authors of [8]. Cement production accounts for approximately 8% of global carbon emissions [9], a gas that contributes to global warming. New technology is necessary to alleviate the negative repercussions of the cement trade [10–11]. The ceramic powder is made from ceramic tiles containing a lot of calcium (Ca) and has better properties than concrete [12]. The compression zone of concrete is stronger than the tension zone. Although fibers are used to strengthen concrete [13,14], aggregate texture substantially influences its strength development. The concrete should be tested for fire resistance at various temperatures [15]. GGBS and ash are the most common industrial byproducts of the GPC process. Several mineral binders have chemical compositions similar to minerals, which a Frenchman named geopolymers in 1978. Geopolymers are largely made up of alkali and source activators. GPC power gel is made from alkali-resolution silicon dioxide and alumina. According to [16], geopolymer concrete is environmentally friendly. He employs waste products from industries such as fly ash, metakaolin, GGBS, and other raw materials. Currently, the construction industry is requesting that cement manufacturing be replaced with industrial byproducts that emit fewer pollutants into the atmosphere.As a result, geopolymer is a special binder that may replace cement in concrete manufacturing. Then, GPC, silica (Si), and alumina (Al) rich raw materials were mixed with an alkaline activator to create the final product. The literature found that fly ash might be used successfully as a base material for GPC. To get its initial strength increased, GPC must cure for 24 hours at 60°C. Using geopolymer concrete on a construction site may be difficult because of the heat-curing required. In precast applications, heat curing is crucial. As a result, GPC is a fantastic choice. All constructions require more durability, which GPC can provide. GGBS and fly ash are the most prevalent industrial byproducts utilized in manufacturing GPC. The author of [17] in 1978 used the word "geopolymer" to characterize chemical compositions comparable to zeolite. [18] The silica and alumina in geopolymer are activated by alkaline solutions, producing a gel that gives GPC its strength. Geopolymers are cementitious compounds having a wide range of civil infrastructure applications. Alkaline activators make sodium aluminosilicate hydrate gel, stabilizing the aggregates and unreacted components, culminating in the production of the geopolymer. Because GPCs made from fly ash require high temperatures for polymerization, the specimens are typically cured at 40–70 °C for 24 to 48 hours [19]. Even though research in geopolymer concrete is being conducted, it is probable that [20] was the first to investigate a slag with alkaline activation. Many researchers then looked into alkali-activated slag to determine whether it might be used instead of standard Portland cement (OPC). The strength of geopolymer has been assessed using high calcium fly ash by [21] adding calcium chloride at 1% and sugar at 2% by weight of fly ash. It has been discovered that adding calcium chloride decreases the initial sucrose and delays the final setting time. According to the findings of this study, 1% gives better benefits than 2%. The author of [22] studied a fly ash-based experiment in which sodium silicate (0, 1, 1.5, 2, and 2.5) was infused into sodium hydroxide (0, 1, 1.5, 2, and 2.5) for 24 hours at 80 degrees Celsius. Because of its homogenous and less porous matrix, its strength is maximum at a sodium silicate ratio of one. According to the study, strength increases with age. The author of [23], the impact of alkaline activator compositions using fly ash and GGBS. The Na2O content of fly ash samples should be higher than that of GGBS. [24] Different molarities ranging from 8M to 16M with strength ratios of 1, 2, 3, and 4 were tested at different oven temperatures to determine their typical consistency. In alkaline liquid ratios of 1.5 and 2, the sodium hydroxide concentration rose with increasing setting time (8 M and 12 M). As the concentration of sodium hydroxide increased, the setting time reduced. Furthermore, the temperature directly impacted the time it took to set. Because of the higher temperature, the setting time was considerably decreased. The author of [25] studied the properties of geopolymer mortar with different molarities (8M, 12M, and 16M) used in 24-hour ambient and heat-curing investigations at 60 °C. The use of GGBS reduced setting time and eliminated the need for oven curing. It is also possible to get the required strength by just curing outdoors. A previous study has found that the molar ratio of Na_2SiO_3/NaOH impacts the properties of geopolymers. According to studies, a ratio of 2.5 and a constant binder concentration can offer maximal compressive strength [26]. According to [27–29] studies, pre-curing fly ash-based GPC at room temperature for a longer time increased strength development. In terms of ultimate strength, NaOH-activated geopolymers outperformed sodium silicate-activated geopolymers. According to a [30–31] study, the quality of GPC is affected by the modification of NaOH, strength ratio, and oven curing. After 24 hours of curing at 60° C, the maximum compressive strength was attained with an alkaline binder ratio of 2, 12M, and a strength ratio of 2.5. The concentrations of NaOH solution (3M, 5M, and 7M) and the GGBS content in fly ash (100, 75, and 50 percent) were varied by the author of [32].The results showed that increasing the concentration of sodium hydroxide solution resulted in higher compressive strength. GPC had a maximum compressive strength of 60 MPa at 28 days with a full sodium hydroxide content (7M). According to [33], temperature significantly impacts the polymerization of geopolymer concrete. Curing at higher temperatures (60°C to 90°C) increases strength. The author of [34] evaluated the effect of workability on the properties of fresh and cured geopolymer concrete containing fly ash. With an oven curing for 24 hours at 60°C, the sodium hydroxide concentrations were determined to be 10, 12M, 14M, and 16M, and the sodium hydroxide to sodium silicate ratio was 2.5. According to the experimental findings, increasing the sodium hydroxide concentration induces a decrease in workability and a rise in compressive strength in GPC. The compressive strength of each NaOH concentration increases with age. [35] investigated how to fly ash-based geopolymers were established using various factors such as the quantity of sodium hydroxide, the strength ratio, and the curing method. In this experiment, increasing the concentration of sodium hydroxide resulted in increased compressive strength. The curing temperature of a geopolymer also influences its strength.The author of [36] explained that geopolymer is an excellent binder in concrete, displaying good strength, increased durability, and sustainability with variable molarity, curing conditions, and GGBS concentration. In preparing Geopolymer Mortar, sodium hydroxide and sodium silicate are more effective than other alkaline solutions due to their inexpensive and easy availability on the market.

Methodology

MATERIALS USED IN THE INVESTIGATION

Various mixes were suggested based on the fly ash to GGBS ratio. The fly ash to GGBS percentage ratios ranging from 100:0 was to make the raw material. The source material to sand ratio varies by a factor of one. The ratio of sodium silicate to sodium hydroxide was kept constant at 2.5. The molarity of the alkaline activator is adjusted to 8 M and 10 M., The density of mortar, is 2200 kg/m^3. The amount of binder, fine aggregate, and alkaline solutions was estimated using mortar density. An additional 10% water weight was added to the concrete to improve its workability. The chemical composition and mix proportions of mortar are shown in Tables 1 and 2.

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

Table 2. Mix Proportion of Geopolymer mortar

Mixes	**Fly ash (kg/m^3)**	**GGBS (kg/m^3)**	**Fine Aggregate (kg/m^3)**	**NaOH (kg/m^3)**	**Na2SiO3 (kg/m3)**	**Alkaline liquid (kg/m^3)**	**SS/SH ratio**
Mix 1- FA: GGBS- 100:0	880	0	880	125.71	314.29	440	2.5
Mix 2- FA: GGBS- 90:10	792	88	880	125.71	314.29	440	2.5
Mix 3- FA: GGBS-	704	176	880	125.71	314.29	440	2.5

80:20							
Mix 4-FA: GGBS-70:30	616	264	880	125.71	314.29	440	2.5
Mix 5-FA: GGBS-60:40	528	352	880	125.71	314.29	440	2.5
Mix 6-FA: GGBS-50:50	440	440	880	125.71	314.29	440	2.5
Mix 7-FA: GGBS-40:60	352	528	880	125.71	314.29	440	2.5
Mix 8-FA: GGBS-30:70	264	616	880	125.71	314.29	440	2.5
Mix 9-FA: GGBS-20:80	176	704	880	125.71	314.29	440	2.5
Mix 10-FA: GGBS-10:90	88	792	880	125.71	314.29	440	2.5
Mix 11-FA: GGBS-0:100	0	880	880	125.71	314.29	440	2.5

Specimen preparation using geopolymer. The fine aggregate to calcined source material ratio is 1:1, and the alkaline liquid to binder ratio is 0.48. Estimated quantities of raw material, fine aggregate, and alkaline solution Sodium hydroxide have a molarity of 8 to 10. The proportions of calcined source material, fly ash, and GGBS are shown in Table 2. Dissolve 320 g sodium hydroxide flakes in 1 liter distilled water to generate an eight molar sodium hydroxide solution. Before making the mortar, it is combined with sodium silicate. For 2 minutes, the alkaline solution is mixed with fine aggregate, fly ash, and GGBS. This is done in a mortar mixer for 10 minutes to guarantee homogeneity. More water was added to the mortar to make it workable. These novel combinations are coherent and segregation-resistant. It is straightforward to compress the mortar with a table vibrator. Cube mortar specimens are cast in 100mm x 100mm x 100mm steel moulds. The prototypes are demolded and cured in an outdoor oven after 24 hours of casting. Curing in a hot air oven at 600°C for 24 hours for oven-treated specimens, followed by 28 days outdoors. Outdoor curing is adequate to increase strength when GGBS is used instead of fly ash—to make the paste. The binder (fly ash and GGBS) needed a lot of dry mixing to combine evenly. The alkaline solution is hand-integrated with the dry mixture to avoid the aggregation of microscopic particles.

Methods

Normal Consistency: Vicat's technique determines the consistency of fly ash and GGBS pastes, as shown in Fig 1. An alkaline solution is used instead of water. The findings of the standard consistency test are identical to the cement regular consistency testing results. Because of the source materials, a typical geopolymer paste is made in an alkaline solution. The proportion of alkaline activator that permits the plunger of the Vicat apparatus to penetrate to a depth of 33-35 mm from the top of Vicat's mould, as illustrated in Fig 2, defines the standard or typical consistency of the geopolymer paste. According to IS 4031-1988, normal consistency allows the Vicat's plunger of 10mm diameter to penetrate to a point 5mm to 7mm from the bottom of the Vicat's mould. The consistency of the fly ash-GGBS geopolymer paste is determined by creating experimental pastes with varying percentages of alkaline solution and GGBS and evaluating them until the amount of alkaline solution required to achieve the standard consistency is identified. This approach is used to change the amount of an alkaline solution using a variable alkaline liquid ratio (8M and 10M).

Fig 1: Preparation of geopolymer paste to determine normal consistency

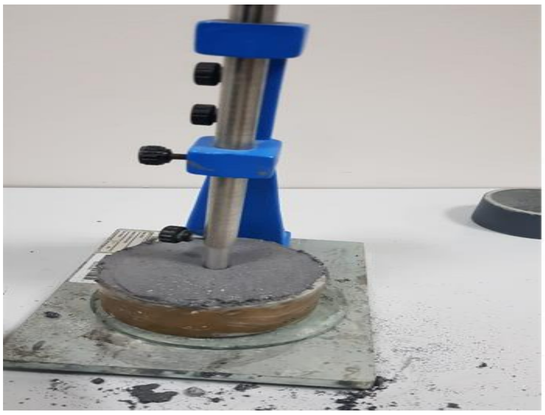

Fig 2: Vicat apparatus with geopolymer paste to determine normal consistency

Setting Time: The alkaline activator solution was manually mixed with the Fly ash in a bowl to ensure reactivity. The Fly ash-GGBS-based geopolymer paste was made right before being mixed with the Fly ash. Instead of cement and water, fly ash-GGBS and alkaline solution are employed in the Portland cement paste requirements. Vicat's apparatus is also used to calculate the ultimate setting time for a combination of fly ash and GGBS paste. An alkaline activator is required 0.85 times more in a standard geopolymer paste. The alkaline Solution (Fly ash and GGBS) is added to the binder during the final setting time, and a 1 mm needle leaves an imprint on the paste in the mould but does not appear with a 5 mm attachment. The amount of AAS utilized impacts how long the geopolymer paste takes to cure (Alkaline activated Solution). According to IS 4031-1988, the setup time is assessed using the Vicat device.
The compression strength of geopolymer mortar: The raw materials Fly ash + GGBS, and alkali binder compressive strength ratios are 1:1. In this experiment, the mixture of both is kept constant. **Tables 6-7** detail the mortar results with various sodium hydroxide concentrations. Few samples are shown in Fig 3

Fig 3: Preparation of geopolymer mortar to determine compression strength

SEM analysis of fly ash and GGBS

The microstructure properties of fly ash and GGBS are studied using SEM (Scanning Electron Microscopy). Fig 4 and 5 exhibit scanned pictures of fly ash and GGBS. The form, angularity, size, and surface texture of fly ash and GGBS can be approximated using scanning electron microscope images. Straight, flaky-elongated GGBS particles with sharp-edged angularity, a rough surface roughness, and a broad range of sizes (1-10 microns) are seen. Across a wide range of sizes, the fly ash particles seem spherical with a smooth surface (the lower limit is roughly 1/10 of the maximum fly ash particle size, i.e., 1 to 10 microns).

ISSN: 2094-0343
2326-9865

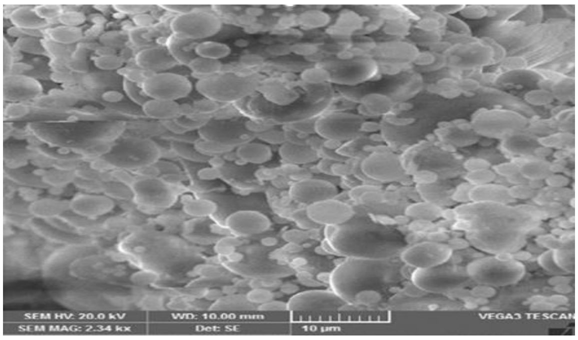

Fig 4: Fly ash Scanned Electron Microscope Image

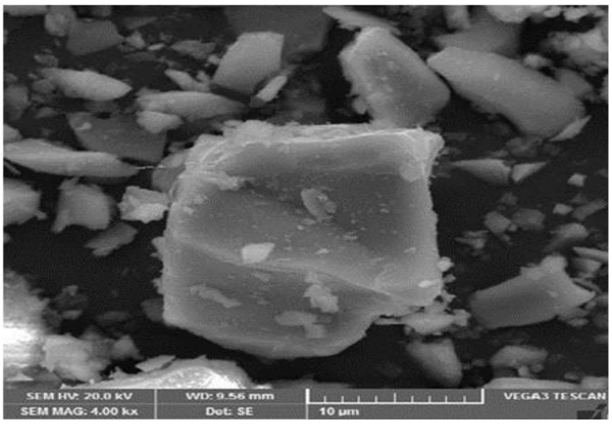

FIG 5: GGBS SCANNED ELECTRON MICROSCOPE IMAGE

GGBS and Fly ash XRD analysis

In a mineralogical investigation, XRD was utilized to describe the mechanical properties of materials. [39] The XRD data were collected using a powder diffractometer with Bragg-Brentano geometry, 30 mA, 40KV, and CuK radiation settings. With 0.05-degree increments, the XRD scanning rate ranges from 10 to 90 degrees per minute. The wavelength of the XRD was 0.154 nm (Cu). X-ray diffraction (XRD) patterns for fly ash and GGBS are shown in Figures 6 and 7, respectively. In his observations, the XRD pattern of raw fly ash is given with a single letter to make it simpler to understand. The crystalline phases quartz (SiO_2) and mullite were discovered using a diffractogram ($Al_6Si_2O_{13}$). The crystalline belt of fly ash links to the summits at an angle of around 26°. The XRD pattern of GGBS is more amorphous when compared to the crystalline phases of fly ash, which comprise crystalline phases of silica and alumina. It has high reactivity and a broad spectrum diffuse band in the 20-40° range.

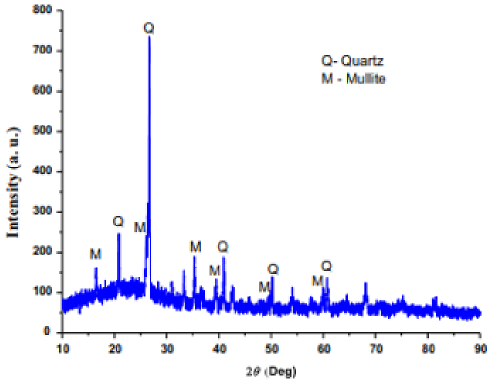

Figure 6: XRD Pattern of Fly ash

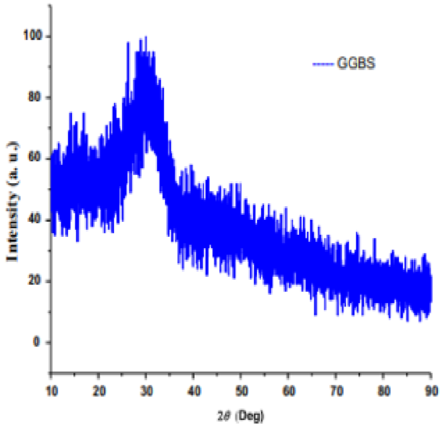

Figure 7: XRD Pattern of GGBS

Elemental Analysis of geopolymer paste samples:

Elemental Analysis is primarily utilized in qualitative and semi-quantitative modes for comparison reasons. The author of [41] explained the elemental analysis activators used to determine the inorganic content by detecting the elements present. Table 3 lists the elements found in geopolymer paste specimens prepared with various GGBS ratios. All samples had high concentrations of silicon, aluminum, and oxygen, indicating the production of alumina-silicate gels. When GGBS was added to the mix, a significant quantity of calcium was detected, indicating the creation of additional calcium silicate hydrates. Furthermore, adding GGBS increased calcium concentration, implying that the synthesis of calcium silicate hydrate gel may also rise.

Table 3: Elemental Analysis of geopolymer paste samples with different amounts of GGBS

Element	**MASS (%)**				
	FAS0	**FAS15**	**FAS30**	**FAS45**	**FAS60**
Carbon	10.89	11.49	7.90	11.47	7.81
Oxygen	46	47	46	43	42.79
Sodium	5.9	6	6	5.8	6.70
Magnesium	0.5	0.91	1.5	1.9	2.54
Aluminum	9	8.6	9.9	9	8.17
Silicon	22.6	19.5	19.6	17	16.61
Sulfur	-	0.1	0.1	0.25	0.3
Calcium	0.7	3.0	5.3	6.9	9.6
Potassium	0.6	0.5	0.5	-	-

RESULTS AND DISCUSSION

Normal consistency:

The average consistency values for various binder content combinations are shown in Table 4. Geopolymer paste (100 percent fly ash, for example) requires less alkaline activator than GGBS paste for better normal consistency (100 percent GGBS content). As a result, the GGBS content of intermediate mixes increases, yielding a higher standard consistency score.

Table 4. Results of Normal Consistency

Fly ash %	GGBS %	The concentration of Sodium Hydroxide	
		8M	10M
100	0	28	28
90	10	27	27
80	20	31	30
70	30	33	31
60	40	33	33
50	50	33	33
40	60	33	33
30	70	33	35
20	80	37	37
10	90	37	37
0	100	37	37

The standard consistency of geopolymer paste is unaffected by changing the NaOH solution concentration and alkaline activator liquid ratios, as shown in the above table. The author of [24] explained that fly ash particles are round and have less internal friction, allowing Vicat's plunger to move readily with a lower alkaline activator level. Compared to fly ash particles, GGBS particles exhibit a straight, flaky-elongated morphology with sharp-edged angularity, abrasive surface roughness, and high internal friction. To obtain normal consistency, they need additional alkaline activators. On the other hand, increase the concentration of NaOH solution from 8M to 10M. Consistency ranges between 28 and 37 percent on average. Geopolymer mortar sets faster than similar due to its alkaline liquid to binder ratio of 0.48. Geopolymer mortars require more time to develop than traditional mortars. As a result, mixing a suitable binder volume with a large GGBS would have significantly reduced the setting time.

Table 5. Results of Final Setting time of paste

Fly ash %	GGBS %	The concentration of Sodium Hydroxide	
		8M	10M
100	0	0	200
90	10	10	185
80	20	20	175
70	30	30	155
60	40	40	130
50	50	50	105
40	60	60	85
30	70	70	76
20	80	80	60
10	90	90	48

0	100	100	42

Setting time:

Setting times increased as the concentration of NaOH solution increased from 8M to 10M, as shown in table 5. The liquid binder is 85 percent of the average consistency percentage for fly ash and GGBS combinations. The tests show that as the amount of GGBS increases, so does the setup time. This action demonstrates that GGBS interacts with the alkaline activator faster than fly ash. The limited reactivity of fly ash often results in delayed settings and strength increase. Fly ash decomposition is frequently not completed before the final cemented structure is built. Mullite in fly ash appears unreacted, although calcium seems active in the alkali activation of ash/slag blends. GGBS with alkaline activator sets up faster than fly ash. As a result, GGBS outperformed fly ash as a source material for geopolymer materials with high early strength.

Table 6: Compressive strengths of geopolymer mortar for the concentration of sodium hydroxide (8M)

Binding Material		**The concentration of Sodium Hydroxide**	
GGBS %	**Fly ash %**	**8M Ambient Curing**	**8M Oven Curing**
0	100	39	41
10	90	42	43
20	80	44	45
30	70	45	46
40	60	47	48
50	50	48	50
60	40	50	51
70	30	52	53
80	20	54	59
90	10	55	62
100	0	59	64

Table 7: Compressive strengths of geopolymer mortars for the concentration of sodium hydroxide (10M)

Binding Material		**The concentration of Sodium Hydroxide**	
GGBS %	**Fly ash %**	**10M Ambient Curing**	**10M Oven Curing**
0	100	41	42
10	90	43	44
20	80	45	47
30	70	47	48
40	60	48	49
50	50	50	52
60	40	52	55
70	30	54	57
80	20	59	60

90	10	63	65
100	0	66	70

The compression strength of mortar:
Tables 6 and 7 illustrate the compressive strengths of geopolymer mortars with variable amounts of fly ash and GGBS and varying sodium hydroxide concentrations in the alkaline activator. In outdoor cured samples, the compressive strength of geopolymer rose as the proportion of fly ash replaced by GGBS increased. After 28 days, the compressive strength of ambient cured geopolymer cement ranges between 39 and 59 MPa. According to the information above, the compressive strength increased as the percentage of GGBFS increased for different fluid to binder ratios. As a result, the amount of binder paste drops, and there is no reaction. The results show how GGBS affects the compressive strength of a Geopolymer mortar cube after 24 hours of ambient and oven curing at 60°C. GGBS enhances the growth of compressive strength. Compared to 1:1, a larger GGBS dose resulted in a higher compressive strength of geopolymer mortar. The compressive strength was maximum when the mixture had 100 percent GGBS and 0 percent GGBS, which declined as the GGBS level was reduced more. Another explanation is that the amount of soluble calcium in the mixture is proportional to the amount of GGBS present, affecting compressive strength instantly. This study examines how curing temperature and time affect compressive strength and cure under external environmental conditions. The strength of mortar treated in an oven is higher than that of geopolymer cured at room temperature. Because the polymerization process is typically expedited at temperatures higher than ambient, the strength gain is even more effective. However, curing at room temperature is critical in terms of practical application. As a result, this research aimed to create a geopolymer mortar out of fly ash and ground granulated blast slag. The most significant gain from oven curing is 64 MPa, while the most incredible increase from outdoor curing is 59 MPa for 8 Molarity. With the inclusion of GGBS, it produces adequate results without the need for oven curing; consequently, oven curing is eliminated if fly ash is replaced with GGBS.
The compressive strength of an alkaline activated Solution (NaOH solution) is affected by its molarity. The effect of alkaline activated solution molarity on compressive strength is seen in Table 5. A high molarity-based alkaline solution boosts compressive strength by increasing silica and alumina dissolving in the binder content and the polymerization process. The influence of the binder-to-fine-aggregate ratio Sand acts as a filler in geopolymer mortar cubes made with fly ash and GGBS, reducing cracking and increasing porosity. It also minimizes the amount of binder paste used, lowering the finished product cost. Therefore, Geopolymer mortar cubes are more prominent than cement mortar cubes. According to the author of [36], the compressive strength results show that the addition of Fly ash and GGBS mixes, including alkali activator (NaOH) and Na2SiO3, can produce a strong cementing material without the inclusion of cementing material due to polymerization**.**

CONCLUSION
Geopolymer paste with 100 percent fly ash needs less alkaline activator for normal consistency than geopolymer paste containing 100 percent GGBS. In intermediate mixes, increasing the GGBS content resulted in a higher normal consistency value. This effect is explained by the

fact that fly ash particles are spherical and have less internal friction, enabling Vicat's plunger to move freely, resulting in lower alkaline activator concentration. GGBS particles have a straight, flaky-elongated morphology with sharp-edged angularity, harsh surface roughness, and solid internal friction, requiring an additional alkaline activator to achieve normal consistency. The increased sodium hydroxide content in the alkaline activator of calcined materials (fly ash and GGBS) does not affect normal consistency. The final setting time, on the other hand, clearly shows that the GGBS reacts with the alkaline activator quickly. Fly ash takes a long time to set and acquire strength due to its low reactivity. In addition, the dissolution of fly ash is not usually complete before the final cemented structure occurs. As a result, GGBS with alkaline activator sets faster than fly ash. Geopolymer's quick setting tendency is troublesome in a traditional building.

Consequently, a good mixture of GGBS and fly ash may be recommended to reach the final setting time value. Furthermore, for geopolymer mortar, a high molarity sodium hydroxide solution in the alkaline activator resulted in greater compressive strength of the geopolymer mortar for all combinations of GGBS and fly ash as source material. Mixing fly ash and GGBS to produce geopolymer concrete in an outdoor curing environment might be a viable option. The curing procedure is critical in the polymerisation process.

REFERENCES

1. Paloma, A.; Grutzeck, M.W.; and Blanco, M.T. (1999). Alkali-Activated Fly Ashes, A Cement for the Future, Cement and Concrete Research, 29(8), 1323-1329.
2. Xu, H.; and Van, DJSJ (2000). The polymerization of aluminosilicate minerals, International Journal of Mineral Processing, 59(3), 247-266.
3. Jaarsveld, J.; Deventer, J; and Lukey, G. (2003). The Characterization of Source Materials in Fly Ash-based Geopolymers, Materials Letters, 57(7), 1272-1280.
4. Cheng, T.W.; and Chiu, J.P. (2003). Fire-resistant Geopolymer Produced by Granulated Blast Furnace Slag, Minerals Engineering, 16(3) 205- 210
5. Djwantoro, H.; Chua, C.; and Lee, C.H. (2008). Strength and Setting Times of Low Calcium Fly Ash-based Geopolymer Mortar." Modern Applied Science, 2, 3-11.
6. Manjunath, G.S.; and Jadhav, M. (2011). Compressive Strength Development in Ambient Cured Geopolymer Mortar." International Journal of Earth Sciences & Engineering. 04, 830-34.
7. Sahana, R. (2013). Setting time compressive strength and microstructure of geopolymer paste. Proceedings of International Conference on Energy and Environment, 2(1)
8. Deb, P.S.; Nath, P.; and Sarker, P.K. (2014). The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature. Materials & Design, 62, 32-9.
9. Lehne, J.; and Felix, P. (2018). "Making concrete change innovation in low-carbon cement and concrete", Chatham House, 2018.
10. Nouby M. Ghazaly, M. M. A. . (2022). A Review on Engine Fault Diagnosis through Vibration Analysis . International Journal on Recent Technologies in Mechanical and Electrical Engineering, 9(2), 01–06. https://doi.org/10.17762/ijrmee.v9i2.364

11. Poloju, K.K. (2022). Industrial wastes as a cement substitute in concrete production", Advanced Materials and Sustainability in Civil Engineering", Springer Briefs in Applied Sciences and Technology, 1st Edition, Springer Singapore, DOI:10.1007/978-981-16-5949-2
12. Poloju, K.K.; Adesh, S.; Zahid; Abdul, R.A.B.; and Shadha, R.A.M. (2020). Determınatıon of strength propertıes of concrete wıth marble powder", International Journal of Advanced Science and Technology, **29**(08), 4004-4008.
13. http://sersc.org/journals/index.php/IJAST/article/view/26213
14. Poloju, K.K.; Al-Ruqaishi, A.Z.M.; and Allamki, MSHA (2019). The advancement of ceramic waste in concrete, International Journal of Advanced and Applied Sciences, **6**(11): 102-108.
15. http://science-gate.com/IJAAS/Articles/2019/2019-6-11/1021833ijaas201911013.pdf. https://doi.org/10.21833/ijaas.2019.11.013
16. Poloju, K.K.; Haitham, S. D.; and Mohamed, AMJT (2017). An Experimental study on compressive strength of sustainable concrete using ceramic waste as partial replacement of cement", Elixir International journal/ Elixir Civil Eng. **107** (2017) 46954-44956
17. https://www.elixirpublishers.com/articles/1496752043_ELIXIR2017055729.pdf
18. Poloju, K.K.; Rahul, C.; and Anil, V. (2018). Glass fiber reinforced concrete (GFRC) - strength and stress-strain behavior for different grades of concrete, International Journal of Engineering & Technology, **7**(4.5), 707-712, Doi: http://dx.doi.org/10.14419/ijet.v7i4.5.25064.
19. Poloju, K.K.; Ram, K.M.; and Rahul, C. (2018). Strength studies on different grades of concrete considering fire exposure, American Journal of Civil Engineering. **6** (1), 16-23. Doi: 10.11648/j.ajce.20180601.14
20. http://www.sciencepublishinggroup.com/journal/paperinfo?journalid=229
21. Poloju, K.K.; Ram, K.M.; and Anil, V. (2017). Properties of concrete as influenced by shape and texture of fine aggregate, American Journal of Applied Scientific Research. **3**(3), 28-36.
22. Doi: 10.11648/j.ajasr.20170303.12.
23. http://www.sciencepublishinggroup.com/journal/paperinfo?journalid=395
24. Davidovits, J.; Comrie, D. C.; Paterson, J. H.; and Ritcey, D.J. (1990). Geopolymeric concretes for environmental protection, Concrete International, 12(7), 30-40
25. Hardjito, D.; Wallah, S.E.; Sumajouw, D.M.J.; and Rangan, B. (2005). Sulfate and acid resistance of fly ash-based geopolymer concrete, Proceeding of Australian Structural Engineering Conference (ASEC), September 2005, Newcastle
26. Purdon, A.O. (1940). The action of alkalis on blast furnace slag, Journal of the Society of Chemical Industry, 59(9), 191-202
27. Rattanasak, U.; Pankhet, K.; and Chindaprasirt, P. (2011). Effect of chemical admixtures on properties of high-calcium fly ash geopolymer, International Journal of Minerals, Metallurgy, and Materials, 18(3), 364-369
28. Morsy, M. S.; Alsayed, S.H.; Al-Salloum, Y.; and Almusallam, T. (2014). Effect of sodium silicate to sodium hydroxide ratios on strength and microstructure of fly ash geopolymer binder, Arabian Journal for Science and Engineering, 39(6), 4333-4339
29. Deb, P.S.; Nath, P.; and Sarker, P. K. (2014). The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature", Materials & Design (1980-2015), 62, .32-39

30. Chaudhary, D. S. . (2022). Analysis of Concept of Big Data Process, Strategies, Adoption and Implementation. International Journal on Future Revolution in Computer Science &Amp; Communication Engineering, 8(1), 05–08. https://doi.org/10.17762/ijfrcsce.v8i1.2065
31. Mallikarjuna, R. G.; Gunneswara, R.T.D.; Ramaseshu, D.; and Venkatesh, A. (2016). Mix Proportioning of geopolymer Concrete, Cement Wapno Beton, 21
32. Rao, G., M.; and Rao, T. G. (2015). Final setting time and compressive strength of fly ash and GGBS-based geopolymer paste and mortar", Arabian Journal for Science and Engineering, 40(11), 3067-3074
33. Pinto, A.T.(2004), "Alkali-activated metakaolin-based binders", (Doctoral dissertation, Ph.D. Thesis. University of Minho).
34. Bakharev, T.; Sanjayan, J.G.; and Cheng, Y., B. (2001). Resistance of alkali-activated slag concrete to alkali-aggregate reaction, Cement and Concrete Research, 31(2), 331-334.
35. Bakharev T, (2005). The durability of geopolymer materials in sodium and magnesium sulfate solutions, Cement and Concrete Research, 35(6), 1233-1246.
36. Parthiban, K.; Saravanarajamohan, K.; Shobana, S.; and Bhaskar, AA (2013). Effect of replacement of slag on the mechanical properties of fly ash-based geopolymer concrete, International Journal of Engineering and Technology (IJET), 5(3), pp.2555-2559
37. Mustafa, A. B.; Kamarudin, H.; Bnhussain, M.; Rafiza, A. R.; and Zarina, Y. (2012). Effect of Na2SiO3/NaOH Ratios and NaOH Molarities on Compressive Strength of Fly-Ash-Based Geopolymer, ACI Materials Journal, 109(5).
38. Poloju, K.K.; and Srinivasu, K. (2022). Influence of GGBS and concentration of sodium hydroxide on strength behavior of geopolymer mortar,_Materials Today: Proceedings, ISSN 2214-7853
39. https://doi.org/10.1016/j.matpr.2022.03.276.
40. Poloju, K.K.; Rahul, C.R.; and Ram, K.M. (2020). A Study on Effect of alkaline activator on strength properties of geopolymer concrete, International Journal of Engineering Research and Management (IJERM) ISSN: 2349- 2058, Special Issue, November 2020
41. Poloju, K.K.; Srinivasu, K.; and Mallikarjuna, R.G. (2020). Study on Mechanical Characterization of Geopolymer Cement Mortar with Single Solution and Combined Solution", Journal of Xi'an University of Architecture & Technology, ISSN No: 1006-7930, XII, (VIII), 481-487
42. Gupta, D. J. . (2022). A Study on Various Cloud Computing Technologies, Implementation Process, Categories and Application Use in Organisation. International Journal on Future Revolution in Computer Science &Amp; Communication Engineering, 8(1), 09–12. https://doi.org/10.17762/ijfrcsce.v8i1.2064
43. J. . Hermina, N. S. . Karpagam, P. . Deepika, D. S. . Jeslet, and D. Komarasamy, “A Novel Approach to Detect Social Distancing Among People in College Campus”, Int J Intell Syst Appl Eng, vol. 10, no. 2, pp. 153–158, May 2022.
44. Rao, M.; Satheesh, K.; Poloju, K.K.; and Srinivasu, K. (2020). An Emphasis of Geopolymer Concrete with Single Activator and Conventional Concrete with Recycled Aggregate and Data Analyzing using Artificial Neural Network, 3rd International Congress on Advances in Mechanical Sciences, IOP Conf. Series: Materials Science and Engineering, 998 (2020) 012060

45. Poloju, K., K.; and Srinivasu, K. (2021). Influence of GGBS and Alkaline Ratio on Compression Strength of Geopolymer Concrete", SPAST Abstracts, 1 (01).
46. Wan H,; Shui, Z.; and Lin, Z. (2004). Analysis of geometric characteristics of GGBS particles and their influences on cement properties", Cement and concrete research, 34(1), 133-137
47. Poloju, K., K.; and Srinivasu, K. (2022), The Method for Determining the Effect of Binder ratio and Different Curing Methods on Strength Parameters of Geopolymer Concrete, Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition),41(5), DOI 10.17605/OSF.IO/QP4ZW
48. IS: 4031, chemical analysis and tests on cement.
49. Ryu, G., S.; Lee, Y., B.; Koh, K., T.; and Chung, Y., S. (2013), The mechanical properties of fly ash-based geopolymer concrete with alkaline activators. Construction and Building Materials, **47,**409–418
50. Nagajothi, S.; Elavenil, S. (2021), Effect of GGBS Addition on Reactivity and Microstructure Properties of Ambient Cured Fly Ash Based Geopolymer Concrete. Silicon **13,** 507–516. https://doi.org/10.1007/s12633-020-00470-w
51. Ananthapadmanaban, D. (2018), Summary of Some Selected Characterization Methods of Geopolymers', in M. Alshaaer, H. Jeon (eds.), Geopolymers and Other Geosynthetics, Intech Open, London. 10.5772/intechopen.82208.
52. M. . Parhi, A. . Roul, B. Ghosh, and A. Pati, “IOATS: an Intelligent Online Attendance Tracking System based on Facial Recognition and Edge Computing”, Int J Intell Syst Appl Eng, vol. 10, no. 2, pp. 252–259, May 2022.
53. Apriany S.; Yuko, O.; Kenji, K.(2019), Effect of GGBS Addition on Properties of Fly ash-based Geopolymer Concrete at High Temperatures, **41**(1)

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