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Effect of Different Proportions of Fly Ash and GGBFS on the Compressive Strength of Geopolymer Mortar

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ABSTRACT

Nowadays, geopolymer plays a significant role in developing eco-friendly materials to avoid the pollution caused by the Portland cement industry. Geopolymer is a developed industrial by-product-based alternative concrete binder. The aim of this study to evaluate the effect of different proportions of Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) on the strength properties of geopolymer mortar. In this study, GGBFS was added as 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of the total binder with NaOH concentrations 12 M and sodium silicate to sodium hydroxide ratio 2.5. The compressive strength was investigated experimentally in this study. The combination of FA and GGBFS were tested in a total of eleven geopolymer mix mortars, and the results show that combining the above constituents at 70°C improves the compressive strength of geopolymer mortar. The result show that the mixture with 100% GGBFS replacement have maximum compressive strength (78.25 MPa) at 7-days age.

1. INTRODUCTION

Because of higher amounts of CO_2 released through the manufacturing process of Portland Cement (PC) clinker, the PC manufacturing business is under careful scrutiny these days. Some estimations state that the cement sector accounts for up to 5% of total world anthropogenic CO_2 emissions [1]. The PC sector, without a doubt, takes the subject of sustainable development extremely seriously. The world's largest cement company, Lafarge, has just produced a corporate report on economic, sociological, and environmental performance that exemplifies this.

Clinker limestone is roasted with a supply of silica in a kiln at temperatures far over 1350°C to generate PC. A 0.55 tonnes of CO_2 emit from producing one tonne of cement in the form of chemical CO_2 and 0.395 tonnes of CO_2 in the form of fuel emissions from grinding and baking., totaling 0.94 tonnes of CO_2 emissions [2]. Damtoft et al. [3] mentioned that the PC industry released 0.87 kg of CO_2 for each kilogram of cement manufactured in 2000.

The cement production is estimated to be over 3*109 tonnes each year. By 2050, global consumption will have climbed by over 200 percent above 2010 levels, especially concerning in present context of carbon dioxide emissions caused global climate change., which is causing the sea level to increase and incidence of natural disasters, as well as being the cause of a future global economic crisis [4]. Also, there is a requirement for more lasting binders stems from the fact that degradation of reinforced PC concrete construction is a typical occurrence.

PC concrete has greater permeability, allowing water to penetrate, resulting in the carbonation and chloride ion assault, which causes corrosion. This necessitates costly conservation efforts or the construction of new ones. So far, research into geopolymeric binders has shown that this new material has a lot of promise to replace PC. Due to the necessity to reduce greenhouse gas emissions caused by PC and the demand for novel binders with improved durability performance, geopolymeric concrete has gotten a lot of attention [5].

Although some research in this subject has been referred to binders with "alkali-activated", the word "geopolymer" is the most often used term. Geopolymerisation is a chemical reaction that occurs when different alumino-silicate oxides react with the silicates under very the alkaline circumstances, resulting in polymeric Si–O–Al– O linkages, implying that any Si – Al substance might be used as a source of geopolymerisation. In comparison to PC, a Geopolymeric binder emits 80% less carbon dioxide [6].

Weil et al. [7] found that the geopolymeric concrete has a 70% lower global warming potential than PC concrete. One of the primary problems that currently remains a significant disadvantage over PC is the high cost of geopolymeric binders [8]. Currently, geopolymeric binders are only cost-effective for structural applications with high performance. In the medium term, the disadvantage noted above indicates that research into applications of geopolymeric must address on the cost of materials like mortars for commercial use. Pacheco-Torgal et al. [9] mentioned that the mortar of geopolymeric can be up to 7 times less expensive than existing the commercial repair mortars. However, when the cost of the lowest commercial repair mortar is compared to the cost of the geopolymeric mortars, the discrepancies are much greater, with the repair mortar cost being 13.8 times greater than cost of geopolymeric mortars.

Chindaprasirt et al. [10] show that the inclusion of an upper plasticizer improves the workability of geopolymeric mortars, but it can also reduce the strength depending on the sodium silicate to sodium hydroxide (NaOH) ratio. Joseph Davidovits developed geopolymer mortar in 1978, which is a binder material made from an alumino-silicate activated in a solution with high alkali. Sodium hydroxide (NaOH) and Sodium silicate were combined to make the alkaline solution utilized in the study.

Because viscous compounds like Sodium silicate and sodium hydroxide are used in concretes and geopolymeric mortars, they have a hard workability. The limited workability of geopolymeric mortars has been blamed by several authors for placement issues. superplasticizers used in PC concrete reduce their fluidifying capabilities for the geopolymeric mortars [11]. Sathonsaowaphak et al. [12] found that the ratio of sodium silicate to Sodium hydroxide (NaOH) and Sodium hydroxide (NaOH) concentrations are 0.670–1.50 and 7.50–12.50 M, respectively.

Aboutalebi et al. [13] found that the optimized condition of H_2O/R_2O, Na_2O/K_2O, R_2O/Al_2O_3 and SiO_2/Al_2O_3 ratios to achieve higher compressive strength should be10-11, 0.6-1, 1.0-1.2, and 3.6-3.8, respectively.

Rangan [14] found that adding a superplasticizer based on naphthalene sulfonate increases the FA geopolymer mixtures workability. A superplasticizer component of more than 2% in a geopolymer combination, alternatively, causes a minor loss of strength. As a result, the goal of this research is to figure out how the geopolymeric mortars composition affects their compressive strength.

The result of Raj et al. [15] indicate that adding ordinary PC to geopolymer PC has an important effect on compressive strength. The mix with 14M NaOH, 20% ordinary PC, curing time of 36 h, ratio of alkaline solutions 2.5, curing temperature of 60℃, a rest period of 48 h and alkaline activator solutions to FA ratio 0.3 had the highest compressive strength.

Improved rubberized geopolymer composites with regard to ductility and thermal characteristics are developed by Abd-Elaty et al. [16]. The influence of crumb rubber content and size on the mechanical, physical, and thermal properties have been studied. They investigated the use of recycled crumb rubber as a partial replacement of sand with (10%, 20%, and 30%) replacement ratios. The results showed that, while the mechanical properties of rubberized geopolymer mortars are typically lower, the mode of failure, toughness, and flexural performance have been significantly improved due to the synergistic interaction of rubber and fibers.

Chen et al. [17] investigate the development of flexural strength, compressive strength, and hydration temperature by adding triethanolamine, triisopropylamine and lithium carbonate to a slag silica fume-based geopolymer mortar at 10℃. The findings demonstrate that lithium carbonate, triethanolamine, and triisopropylamine can improve the early mechanical properties of a geopolymer mortar based on slag silica fume. The optimum concentrations of lithium carbonate, triethanolamine, and triisopropylamine are 0.04%, 0.06%, and 0.4%, respectively.

Rathanasalam et al. [18] present the properties of blended geopolymer concrete made using ultrafine GGBFS and fly ash, as well as copper slag as a substitute for fine aggregate. Experimental results show that the addition of ultrafine GGBFS to geopolymer concrete improved its strength performance.

The goal of this study is to assess the performance of FA-based geopolymer and alkali activated as a replacement for ordinary PC in mortar production. This study includes the strength improvement of FA-based geopolymer and alkali activated mortar to replace GGBFS as a binder, the improvement of FA-based geopolymer strength, and the performance of fly ash-based geopolymer and alkali activated mortar in terms of compressive strength properties. The research adds to the creation of new ecologically friendly binders by building on previous research.

2. EXPERIMENTAL PROGRAM

The present experimental work addressed on compressive strength FA-based GM for various aggregates grading and types.

2.1 Materials

In an alkaline environment, two pozzolanic materials, GGBFS and FA, were used as binding components to create geopolymer mortar. FA conforming to ASTM C618-08 [19] and GGBFS conforming to ASTM C-989. Table 1 shows the chemical and physical parameters of GGBFS and FA as determined by X-ray fluorescence (XRF).

Locally, sodium hydroxide in flake form with a purity of 98 percent is available. To make a solution with the desired concentration, distilled water must be used to dissolve the solids. The solution of Geopolymer mortar is made using sodium hydroxide. NaOH flakes with a purity of 98 percent, as shown in Figure 1, were purchased from a chemical supplier and utilized to make the NaOH solution. Table 2 provides more information on the sodium hydroxide solution utilized in this study according to ASTM E291-09.

Table 1. Properties of GGBFS and FA

Chemical and Physical Analysis	FA	GGBFS
CaO (%)	2.20	34.120
SiO_2 (%)	57.20	36.410
Specific gravity	2.250	2.610
Fe_2O_3 (%)	7.10	0.690
Loss of ignition (%)	1.50	1.640
SO_3 (%)	0.3	0.3
Na_2O (%)	0.40	0.350
K_2O (%)	3.40	0.970
Al_2O_3 (%)	24.40	10.390
MgO (%)	2.40	10.260
Specific surface area (m^2/kg)	379. 0	418. 0
CaO (%)	2.20	34.120

Table 2. Properties of sodium hydroxide

Appearance	Unit measuring	ASTM E291-090 Specification	Results
NaOH, min.	%	≥ 97.50	98.140
NaCl, max.	%	0.150	0.070
Na_2CO_3, max	%	0.400	0.360
Copper as Cu^{+2}	Ppm	≤4.00	0.10
Fe_2O_3, max.	%	0.010	0.0050
Na_2SO_4	Ppm	≤200.	70.0
Silicate as SiO_2	Ppm	≤20.0	14.0
Nickel as Ni^{+2}	Ppm	≤5.00	2.420
Mn	Ppm	≤4.00	0.020

The ratio of Na_2O to SiO_2 and H_2O determines the sodium silicate concentration. The sodium silicate solution (water glass) has a composition of 29.40 present SiO_2, 14.7 percent Na_2O, and 55.990 percent water. The characteristics of sodium silicate utilized are seen in Table 3.

The plasticizer, a high range water reduction superplasticizer based on polycarboxylic ether, is used to increase the geopolymer concrete workability with the addition of water and is used as 5% of the binder. This superplasticiser is a liquid that meets ASTM C494-2005 specifications. The features of superplasticizer SP1 are summarized in Table 4.

The natural sand was used as fine aggregate in this study. Tests were performed to measure the gradation and specific gravity. The fine aggregate used in this work conforming to Iraqi Standard IQS 45-1984 [20], the specific gravity was 2.6.

Figure 1. Sodium hydroxide

Table 3. Sodium silicate properties

	Value
Density - 20° Baumé	51± 0.50
SiO_2 percent by weight	32.0-33.0
Na_2O percent by weight	13.1-13.7
Viscosity (CPS) 20°C	600.0-1200.0
Specific Gravity	1.5340-1.5510
Appearance	Hazy

Table 4. Superplasticizer (SP1) properties

Property	Description
Chloride content	< 0.1%
Alkaline content	< 3%
Air entrainment	Maximum 1%
Specific gravity	1.07 at 25°C
Freezing point	0%
Colour	Dark brown / black liquid

2.2 Mix proportions and testing procedure

A total of eleven mixtures were made by varying the percentages of FA and GGBFS content. For about 2 minutes, the binder and aggregate were mixed together in a rotary mixer. Water was then added, and the mixing process was repeated for another 5 minutes to produce the fresh mortar. The designed mixtures were used to investigate the compressive strength of geopolymer mortar under a 24 hour curing duration and a 70°C curing temperature. The entire alkaline solutions amount and the base material make up the binder content in the combinations (GGBFS or FA). The weight of chosen binder is 900 Kg/m^3. Table 5 shows the Geopolymer Mortar (GM) mix design. In all of the mix design, the liquid component was the alkaline solution (without adding water). To increase workability and homogeneity, a superplasticizer with a 1.07 specific gravity is added to the mix. The (Na_2SiO_3: NaOH) ratio and Molarity are equal to 2.5 and 2 respectively for all mixes.

A total of eleven mixes with varying percentages of FA and GGBFS were prepared. For around 2 minutes, the binder and aggregate were mixed together. After that, the liquid of alkaline was mixed with the dry components and mixed for another 5 minutes in order to make fresh mortar, the fresh mortar was compacted.

Six (50×50×50) mm cube specimens were cast for each mortar mixture to find the compressive strength. The specimens were immediately enclosed with plastic film after moulding to reduce the evaporation of water during curing at an elevated temperature. The mortar specimens were cured for 24 hours in a 70°C. The specimens were left in moulds and demoulded after the curing period.

The compressive strength of geopolymer mortar was determined using (50×50×50) mm cubes according to ASTM C39 [21]. The specimens are tested at ages 1 day and 7 days. The specimens remove from the oven after it has been cured and allow it to cool before testing. For accuracy, compressive strength tests are normally done on three specimens, with the average value being taken as the final result, as shown in Figure 2.

Table 5. Geopolymer mortar mix design

Mix.	S. H. Sol. (kg/m^3)	FA (kg/m^3)	GGBFS (kg/m^3)	River sand aggregate (kg/m^3)	Superpla-sticizer (kg/m^3)
M1	85.8	600	0	1298.22	30
M2	85.8	540	60	1307.963	30
M3	85.8	480	120	1317.705	30
M4	85.8	420	180	1327.447	30
M5	85.8	360	240	1337.188	30
M6	85.8	300	300	1346.93	30
M7	85.8	240	360	1356.67	30
M8	85.8	180	420	1366.41	30
M9	85.8	120	480	1376.15	30
M10	85.8	60	540	1385.89	30
M11	85.8	0	600	1995.63	30

Figure 2. Compressive strength test for mortar cube

2.3 Result and discussion

The FA-based GM prepared with various GGBFS mass ratios display dissimilar compressive strength improvements at 24 hours curing age and after 7 days with the same curing. Figures 3, 4 and Table 6 show the test results of FA based GM at six GGBFS ratios.

At the 7-day test, the maximum strength was 78.25 MPa. The results show that compressive strength and GGBFS ratio are proportionally related. The compressive strength was improved by increasing the GGBFS ratio to 100%. This behavior could be explained by the fact that the reaction between silicate and aluminate types is faster than the reaction between only silicate types. The Calcium (Ca) in the GGBFs hydrates and creates a C–S–H gel, which improves the compressive strength properties [22].

The GGBFS raises the Si/Al ratio in mixture, which defines the proportional quantity of AlO_4 and SiO_4 generated in the geopolymer gel and reflects the proportion of Si present in the mix. The Si/Al ratio can also be changed by changing the alkaline solution's composition. With the addition of sodium silicate to the activator solution, the molar ratio of Si/Al rises. The soluble silica presence rapids up the condensation process, allowing more Si to enter the polymeric chain. This improves the strength of the material, which is particularly noticeable at higher curing temperatures [23]. This improves the geopolymer's binding process and characteristics.

From Table 6, it can be observed that the lowest curing time is detected from the samples without GGBFS. This produces the lowest strength improvement among other ratios at all curing time and, as a result, the Geopolymerization reaction is the lowest.

From the Table 6 can be noted that the combination of the FA and GGBFS at 70°C has a positive effect on the strength of geopolymer mortar and can be observed that as the age of sample increases, compressive strength increase with all the ratio of GGBFs content. The mechanical characteristics of FA geopolymer mortar over time are thought to be influenced by age.

Table 6. Compressive strength of geopolymer mortar

Mix. No.	Binder proportion	Compressive strength with 70°C and different duration test (MPa)	
		At 1 Day	At 7 Days
M1	F100-S0	21.5	39.15
M2	F90-S10	26.57	42.43
M3	F80-S20	31.31	46.73
M4	F70-S30	35.78	50.92
M5	F60-S40	39.52	57.29
M6	F50-S50	41.73	59.73
M7	F40-S60	49.51	63.62
M8	F30-S70	55.2	68.69
M9	F20-S80	57.29	70.93
M10	F10-S90	63.34	75.17
M11	F0-S100	70.47	78.25

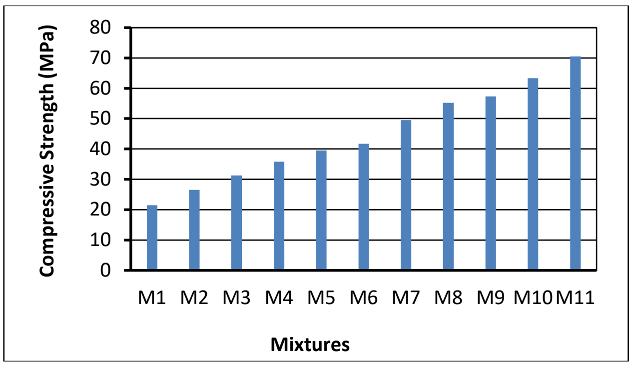

Figure 3. Compressive strength of geopolymer at 1 day with 24h curing duration

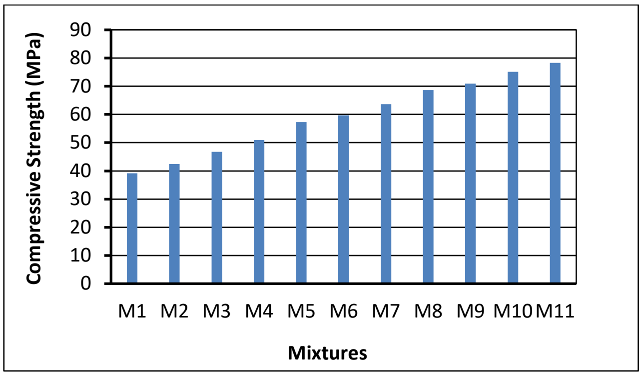

Figure 4. Compressive strength of geopolymer at 7 days with 24h curing duration

3. CONCLUSIONS

The aim of this study to study the effect of different proportions of fly ash and ground granulated blast furnace slag on the compressive strength of geopolymer mortar. The following are the findings of the research:

(1) The mixture with 100% GGBFS replacement has maximum compressive strength (78.25 MPa) at 7-days age.

(2) The results indicate that the combination of the fly ash and GGBFS at 70°C has a positive effect on the compressive strength of geopolymer mortar.

(3) It has been observed that as the age of sample increases, compressive strength increase with all the ratio of GGBFS content.

(4) It has been noted that when the rate of ground granulated blast furnace slag ratio increases, the compressive strength increase for all mixtures at 1 day and 7 days.

REFERENCES

[1] Hendriks, C., Graus, W., van Bergen, F. (2004). Global carbon dioxide storage potential and costs. Ecofys, Utrecht, 64.

[2] Gartner, E. (2004). Industrially interesting approaches to “low-CO_2” cements. Cement and Concrete Research, 34(9): 1489-1498. https://doi.org/10.1016/j.cemconres.2004.01.021

[3] Damtoft, J.S., Lukasik, J., Herfort, D., Sorrentino, D., Gartner, E.M. (2008). Sustainable development and climate change initiatives. Cement and Concrete Research, 38(2): 115-127. https://doi.org/10.1016/j.cemconres.2007.09.008

[4] Stern, N. (2006). Stern review: The economics of climate change.

[5] Duxson, P., Fernández-Jiménez, A., Provis, J.L., Lukey, G.C., Palomo, A., van Deventer, J.S. (2007). Geopolymer technology: The current state of the art. Journal of Materials Science, 42(9): 2917-2933. https://doi.org/10.1007/s10853-006-0637-z

[6] Duxson, P., Van Deventer, J.S.J. (2009). Commercialization of geopolymers for construction–opportunities and obstacles. In Geopolymers, pp. 379-400.

[7] Weil, M., Gasafi, E., Buchwald, A., Dombrowski, K., Buchwald, A. (2005). Sustainable Design of Geopolymers-Integration of economic and

environmental aspects in the early stages of material development. In 11th Annual International Sustainable Development Research Conference.

[8] Davidovits, J. (1999). Chemistry of geopolymeric systems, terminology. In: Proceedings of 99 International Conference. eds. Joseph Davidovits, R. Davidovits & C. James, France.

[9] Pacheco-Torgal, F., Castro-Gomes, J.P., Jalali, S. (2008). Adhesion characterization of tungsten mine waste geopolymeric binder. Influence of OPC concrete substrate surface treatment. Construction and Building Materials, 22(3): 154-161. https://doi.org/10.1016/j.conbuildmat.2006.10.005

[10] Chindaprasirt, P., Chareerat, T., Sirivivatnanon, V. (2007). Workability and strength of coarse high calcium fly ash geopolymer. Cement and Concrete Composites, 29(3): 224-229. https://doi.org/10.1016/j.cemconcomp.2006.11.002

[11] Palacios, M., Puertas, F. (2005). Effect of superplasticizer and shrinkage-reducing admixtures on alkali-activated slag pastes and mortars. Cement and Concrete Research, 35(7): 1358-1367. https://doi.org/10.1016/j.cemconres.2004.10.014

[12] Sathonsaowaphak, A., Chindaprasirt, P., Pimraksa, K. (2009). Workability and strength of lignite bottom ash geopolymer mortar. Journal of Hazardous Materials, 168(1): 44-50. https://doi.org/10.1016/j.jhazmat.2009.01.120

[13] Aboutalebi, S.H., Ganjkhanlou, Y., Kamalloo, A., Nuranian, H. (2010). Modeling of compressive strength of metakaolin based geopolymers by the use of artificial neural network research note. International Journal of Engineering, 23(2): 145-152.

[14] Rangan, B.V. (2009). Engineering properties of geopolymer concrete. In Geopolymers, pp. 211-226.

[15] Raj, S.R., Arulraj, P.G., Anand, N., Balamurali, K., Gokul, G. (2021). Influence of various design parameters on compressive strength of geopolymer concrete: A parametric study by Taguchi method. International Journal of Engineering, 34(10): 2351-2359. https://doi.org/10.5829/ije.2021.34.10a.16

[16] Abd-Elaty, M.A.A., Ghazy, M.F., Khalifa, O.H. (2022). Mechanical and thermal properties of fibrous rubberized geopolymer mortar. Construction and Building Materials, 354: 129192.

[17] Chen, T., Ren, B., Wang, Z., Meng, X., Ning, Y., Lv, Y. (2022). Effect of early strength agent on the hydration of geopolymer mortar at low temperatures. Case Studies in Construction Materials, e01419.

[18] ASTM C618-08. (2008). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. ASTM International. Retrieved 2008-09-18.

[19] Iraqi Specification No. 45. (1984). Natural Sources for Gravel that is Used in Concrete and Construction. Baghdad.

[20] American Society for Testing and Materials: ASTM C39/C39M-1 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Annual Book of ASTM Standard Vol. 4. 02, Philadelphia, PA, USA, (2009).

[21] Kumar, T., Vishwanatham, S., Kundu, S.S. (2010). A laboratory study on pteroyl-L-glutamic acid as a scale prevention inhibitor of calcium carbonate in aqueous solution of synthetic produced water. Journal of Petroleum Science and Engineering, 71(1-2): 1-7. https://doi.org/10.1016/j.petrol.2009.11.014

[22] Chi, M., Huang, R. (2013). Binding mechanism and properties of alkali-activated fly ash/slag mortars. Construction and Building Materials, 40: 291-298. https://doi.org/10.1016/j.conbuildmat.2012.11.003

[23] Criado, M., Fernández-Jiménez, A., Palomo, A. (2007). Alkali activation of fly ash: Effect of the SiO_2/Na_2O ratio: Part I: FTIR study. Microporous and Mesoporous Materials, 106(1-3): 180-191.