



Experimental Evaluation Of The Influence Of Alkaline Solution-To-Fly Ash Ratio And Fine Aggregate Gradation On The Performance Characteristics Of Geopolymer Concrete

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Abstract - Since it uses industrial byproducts, geopolymer concrete (GPC) has been studied as a sustainable construction material option that can reduce CO₂ emissions. Studies done in the past on GPC demonstrate that it may be used structurally, has a workable slump, and has a similar strength grade to regular Portland cement concrete. In order to identify and present the most recent data and information on geopolymer concrete, this study has examined the mix design, mechanical properties, durability, and microstructure of GPC.

An increased focus on energy efficiency and environmental protection has prompted research into alternate building materials. Reducing greenhouse gas emissions and lowering the amount of energy needed for material production are two important objectives for such investigations. Concrete is used more than water anywhere in the world. Traditionally, the main binder for creating concrete has been ordinary Portland Cement (OPC). At least 5 to 7 percent of CO₂ produced worldwide comes from the manufacturing of cement. The proper disposal of fly ash, a hazardous waste product created by thermal power plants through combustion, is another significant environmental issue.

This study gives details about the experimental investigation of geopolymer concrete. It shows that some

parameter were fixed and the two parameters such as water to binder ratio and zones of sand were varied and from that the one having max compressive strength parameter were fixed. After fixing the parameters durability test of on geopolymer concrete of rapid chloride penetration test and acid attack test was conducted and at last XRD test was conducted to know the microstructural investigation on geopolymer concrete. The mix design, mechanical characteristics, durability, and microstructure of GPC have all been studied in this study.

keywords— Geopolymer concrete, Greenhousegases, fly ash, Compressive strength, XRD test .

I. INTRODUCTION

Concrete is the most widely used construction material in the world, second only to water in terms of consumption. It is an essential component of modern infrastructure and development. However, the production of Ordinary Portland Cement (OPC)—the primary binder in conventional concrete—has serious environmental implications. The manufacturing of one tonne of cement releases approximately 0.9 tonnes of carbon dioxide (CO₂) into the atmosphere and consumes significant natural resources such as limestone and fossil fuels. This has raised global concerns about the

sustainability of cement-based construction materials and has led to the search for alternative, eco-friendly binders.

In this context, geopolymers concrete (GPC) has emerged as a sustainable and high-performance alternative to traditional cement concrete. Geopolymer concrete is synthesized through the alkali activation of aluminosilicate-rich industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), metakaolin, or rice husk ash. Instead of using cement, the aluminosilicate source reacts with an alkaline activator solution—usually a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3)—to form a three-dimensional polymeric network. This process, known as geopolymerization, produces a hardened binder with excellent mechanical strength, durability, chemical resistance, and reduced carbon emissions compared to conventional concrete. The performance of geopolymer concrete, however, depends on various mix design parameters. Among these, two of the most critical factors are the solution-to-fly ash ratio (S/F ratio) and the grading or zoning of fine aggregates. The alkaline activator solution plays a key role in initiating and sustaining the geopolymerization reaction. The quantity and concentration of the activator determine the extent of dissolution of silica (Si) and alumina (Al) from fly ash particles, which in turn influences the formation of the geopolymeric gel (N-A-S-H). An optimum S/F ratio ensures adequate reaction between the fly ash and activator solution, leading to improved workability, setting characteristics, and strength development. A higher S/F ratio may enhance reactivity but could lead to excessive heat generation and shrinkage, while a lower ratio may result in incomplete activation and weak bonding.

In addition to the activator ratio, the fine aggregate zoning significantly affects the workability, compaction, and microstructure of the concrete. Aggregates occupy about 70–80% of the total volume of concrete, making their properties crucial to overall performance. The particle size distribution of fine aggregate influences the packing density, void content, and paste requirement. Properly graded aggregates minimize voids and enhance inter-particle contact, resulting in better strength and durability. On the other hand, poorly graded or unbalanced aggregate zones can lead to segregation, bleeding, and increased water or activator demand. Hence, studying the influence of aggregate zoning helps to optimize the density and homogeneity of geopolymer concrete.

The combined influence of the alkaline activator-to-fly ash ratio and the zoning of fine aggregates on the mechanical properties—such as compressive strength, split tensile strength, and flexural strength—remains an area requiring systematic investigation. Previous research has explored the effects of activator concentration, curing temperature, and type of precursor material individually; however, limited attention has been given to the interaction between the activator ratio and aggregate characteristics. Understanding this relationship

is essential for developing mix design guidelines tailored for different sources of fly ash and locally available aggregates.

Moreover, in developing countries like India, the availability and characteristics of fly ash and aggregates vary regionally due to differences in thermal power plant operations and riverbed deposits. Therefore, optimizing the mix design of geopolymer concrete based on local materials can lead to more sustainable and cost-effective construction practices. By controlling the activator content and selecting suitable fine aggregate zones, it is possible to achieve desirable mechanical properties while minimizing material waste and environmental impact.

Thus, the present study aims to evaluate the effect of varying solution (alkaline activator) to fly ash ratios and different zones of fine aggregates on the mechanical properties of geopolymer concrete. The outcomes of this research are expected to provide valuable insights into the mix optimization, performance enhancement, and practical applicability of geopolymer concrete in structural applications. This study contributes toward advancing green concrete technology and supports the broader goal of sustainable infrastructure development.

II. LITERATURE REVIEW

1. Use of geopolymer concrete for a cleaner and sustainable environment. A review of mechanical properties and microstructure

Author: Amer Hassan, Mohammed Arif, M. Shariq

Publication: Journal of Cleaner Production 223, 2019.

Findings:

- The GPC is the best option for the building sector since it has all the desirable mechanical and structural characteristics.
- After reviewing the strength and durability characteristics of GPC, it can be said that it performs much better than OPC concrete in terms of chemical and fire resistance.
- Since GPC generated in an industrial plant may differ from test specimens made in a laboratory, it should be examined for long-term creep and shrinkage qualities.

2. Fly ash fineness – Comparing residue on 45-micron sieve with Blaine's surface area

Author: S.S. Bagchi, S.V. Ghule and R.T. Jadhav

Publication: The Indian Concrete Journal, 2022.

Findings:

- This paper represents the test done on fly ash to check the fineness using the Blaine's apparatus.
- Fly ash type of particles under 10 microns are the ones that contribute to the 7- and 28-days strengths.
- Particles between 10 and 45 microns contribute to strength from 28 days and up to about one year.
- Inert particles behave like sand particles and are regarded to be larger than 45 microns.

3. Correlation between Na₂SiO₃/NaOH Ratio and Fly Ash/Alkaline Activator Ratio to the Strength of Geopolymer

Author: A.M. Mustafa Al Bakri, H. Kamarudin, I. Khairul Nizar, M. B Hussain, Y. Zarina and A. R. Rafiza

Publication: Advanced Materials Research Vols. 341-342, 2011.

Findings:

1. For desired compressive strength, the ratios of the alkaline activator to fly ash and Na₂SiO₃/NaOH are crucial.
2. In order to ascertain the maximum compressive strength, various ratios of the alkaline activator to fly ash and Na₂SiO₃/NaOH were examined.
3. The alkaline activator to fly ash ratios of 0.5 and 0.30 yielded the highest compressive strength.

4. Effect of grading of fine aggregate on flow and compressive strength of geopolymer concrete.

Author: Subhash V Patankar, Sanjay S Jamkar, Yuvraj M Ghugal

Publication: UKIERI Concrete Congress - Innovations in Concrete Construction, 2013.

Findings:

1. Fine aggregate conforming to grading zone-I shows higher flow than that of zone-II, III and IV as it contains coarser sand particles.
2. The grading of the fine aggregate and the quantity of water have negligible effects on the compressive strength of geopolymer concrete with the same water-to-geopolymer binder ratio of 0.35.
3. Fine aggregate conforming to zone-I gives higher density than other three zones for different quantities of water.

5. Effect of Size of Coarse Aggregate on Mechanical Properties of Metakaolin-Based Geopolymer Concrete and Ordinary Concrete

Author: Hamed Fazli, Dongming Yan, Yajun Zhang and Qiang Zeng

Publication: Materials 2021, 14, 3316

Findings:

1. As the size of the coarse aggregate rose, the compressive strength of Geopolymer Concrete dropped.
2. The splitting tensile strength decreased as a result of larger coarse aggregates creating more microcracks nearby.
3. It can be concluded that changes in pore structure that take place when the coarse aggregate size grows have a significant impact on the strength development of the tested specimens.
4. More macropores are produced as a result of MKGP concrete shrinking more quickly when the size of the coarse aggregate increases.

6. Effect of curing condition on strength of geopolymer concrete

Author: Amol A. Patila, H.S. Chore and P.A. Dodeb

Publication: Advances in Concrete Construction, Vol. 2, No. 1 (2014) 29-37

Findings:

1. The parameters such as curing time and curing temperature significantly affect the compressive strength of the hardened geopolymer concrete.
2. In both types of cures taken into consideration in the study, the compressive strength increases with age.
3. Compared to the case of hot curing conditions, the improvement in strength for ambient curing is significant.

7. Investigation of early compressive strength of fly ash-based geopolymer concrete

Author: Lateef N. Assi, Edward (Eddie) Deaver, Mohamed K. El Batanouny, Paul Ziehl.

Publication: Construction and Building Materials 112 (2016) 807–815

Findings:

1. Fly ash-based geopolymer concrete (FGC) was able to achieve a very high early compressive strength using Type F fly ash and a silica fume activating solution.
2. Compared to identical specimens cast using sodium silicate-based activating solution, the silica fume-based activating solution yielded higher compressive strength values.
3. The curing conditions had no discernible impact on the compressive strength when silica fume was added to the activating solution.

8. Mix Design of Fly Ash Based Geopolymer Concrete

Author: Subhash V. Patankar, Yuwaraj M. Ghugal and Sanjay S. Jamkar

Publication: SEC-14, Biannual Conference IIT Delhi, December 2014

Findings:

1. In this research, design recommendations for ordinary and standard grade geopolymer concrete based on fly ash were proposed.
2. Experimental results of geopolymer concrete mixes for grades M20, M25, M30, M35, and M40 using the suggested technique to mix design show good results for workability and compressive strength.
3. These recommendations support the design of the Ordinary and Standard Grades of fly ash-based geopolymer concrete as specified in IS 456: 2000.

Major Findings from literature review

1. The grade of geopolymer concrete to be cast is of M 30 grade.
2. From the F and C classes of the two-fly ash. Fly ash of class F will be used in the design since it is more effective than fly ash of class C.

3. As there are various grades of fly ash such as P10 to P100. The grade of fly ash to be use is P100.

4. The activators used for preparation of geopolymer concrete shall include of the following: a) Sodium Hydroxide b) Sodium silicate

5. The size of Coarse aggregate to be used in design is 20mm.

6. The water used in production of concrete is conform to the requirements specified in IS 456. Water temperature shall be in no case less than 20 °C.

7. Composition:

a) The Ratio of alkaline activator of NaOH and Na₂SiO₃ is taken as 1 as per the experimental investigation.

b) The experimental examination determines that the alkaline activator to fly ash ratio

8. The ideal conditions for curing for fly ash-based mixes is temperature greater than 30 °C and less than 50 °C for 24 hours

III OBJECTIVES OF INVESTIGATION

- To investigate the effect of variation of solution (alkaline activator) to fly ash ratio and zoning of fine aggregate on mechanical properties of geopolymer concrete.
- To check durability aspect of fly ash-based Geo polymer concrete.
- To investigate micro structural properties of geopolymer concrete using XRD test.

IV. MATERIALS

1. Fly ash : Geopolymer concrete can be produced using the low-calcium fly ash derived from coal-burning thermal power plants. A byproduct of burning bituminous or anthracite coal is fly ash., and the bulk of fly ash that is easily available on a global scale is low-calcium fly ash. Despite the fact that coal-burning power plants are viewed as being unfriendly to the environment, the amount of electricity produced by these facilities is increasing because high-quality coal is readily available worldwide and the electricity generated from it is cheap.



Fig no.1: Fly ash.

For this experiment, fly ash with a P100 fineness was collected from the Nashik Thermal Power Plant in the Maharashtra village of Eklahare. The fineness of fly ash was measured using Blanes apparatus. Geo-polymer concrete has been effectively created using low-calcium fly ash when the silicon and aluminum oxides made up around 80% of the bulk, with a Si-to-Al ratio of about 2. The iron oxide content typically ranges from 10% to 20% by mass, while the calcium oxide level is less than 5% by mass. The loss on ignition by mass reveals that the fly ash has a carbon concentration of as little as 2%.

2. Aggregates : All of the test specimens were made using locally accessible, crushed coarse aggregates with a maximum size of 20 mm and 12.5 mm. According to IS: 383-1970, all the aggregate was tested as shown in Table 5.1. Zone I, Zone II, Zone III, and Zone IV are the four zones of fine aggregate used in this work, and their respective fineness moduli are 3.7, 3.3, 2.7, and 2.3. The crush sand, which has a fineness modulus of 3.2 and a specific gravity of 2.72, is frequently utilized as fine aggregate. The fine aggregate was employed in the dry form after being sieved to a size of less than 4.75 mm.

3. Alkaline Liquid Solution : In geopolymer concrete activators like sodium hydroxide and sodium silicate are used. It is advised that the alkaline liquid be made by combining the two solutions at least 30 minutes before to usage. A high range water reducer additional water might be added to the mixture to increase workability.



Fig no. 2: Sodium Hydroxide



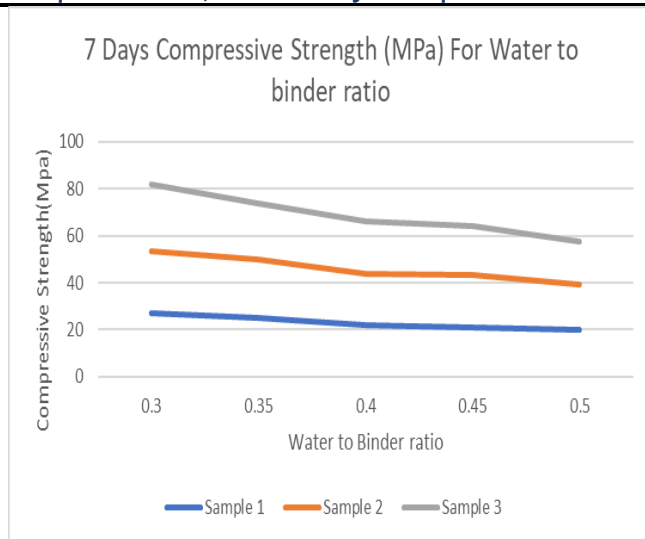
Fig no. 3: Sodium Silicate

V. Testing Program

1. Compressive Strength : The effects of changing the water-to-geopolymer binder ratio while holding all other test variables constant on the compressive strength of geopolymer concrete. It has been shown that when the water-to-geopolymer binder ratio increases, so does the compressive strength of geopolymer concrete. This demonstrates that, similar to cement concrete, the compressive strength of geopolymer concrete is inversely proportional to the water-to-geopolymer binder ratio. This shows that adding water significantly increases the mixture's workability by lowering its viscosity, but at the expense of strength.

Table 1: 7 days Compressive Strength (Mpa) for varying water to binder ratio

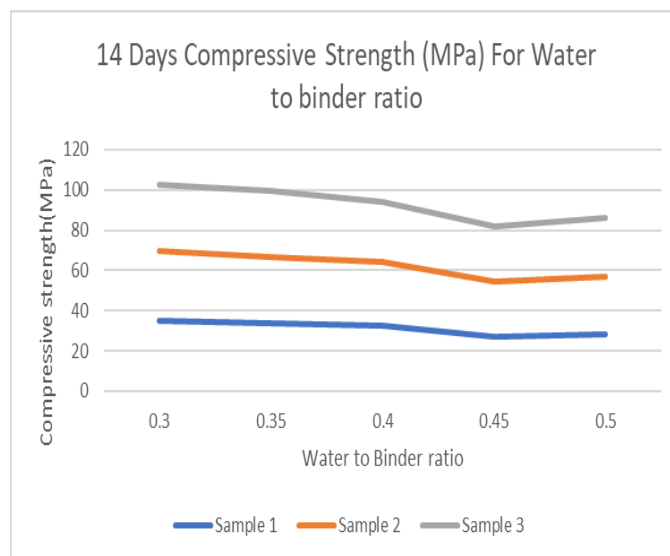
7 days Compressive Strength (Mpa) for different water to binder ratio					
	0.30	0.35	0.40	0.45	0.50
Sample 1	27.05	24.84	21.96	21.14	19.85
Sample 2	26.54	25.07	21.97	22.09	19.58
Sample 3	28.57	23.86	22.07	21.00	18.00



Graph no.1: 7 days Compressive strength (CS) of Geopolymer Concrete

Table 2: 14 days Compressive Strength (Mpa) for varying water to binder ratio

14 days Compressive Strength (Mpa) for different water to binder ratio					
	0.30	0.35	0.40	0.45	0.50
Sample 1	34.87	33.42	32.32	27.14	27.98
Sample 2	34.98	33.00	31.67	27.00	28.93
Sample 3	33.00	32.85	30.00	28.00	29.00



Graph no 2: 14 days Compressive strength (CS) of Geopolymer Concrete

Table 3: 28days Compressive Strength (Mpa) for varying water to binder ratio

28 days Compressive Strength (Mpa) for different water to binder ratio					
	0.30	0.35	0.40	0.45	0.50
Sample 1	46.01	45.16	41.43	38.39	36.46
Sample 2	46.64	45.90	40.00	38.01	35.00
Sample 3	45.04	44.90	39.00	37.09	34.99

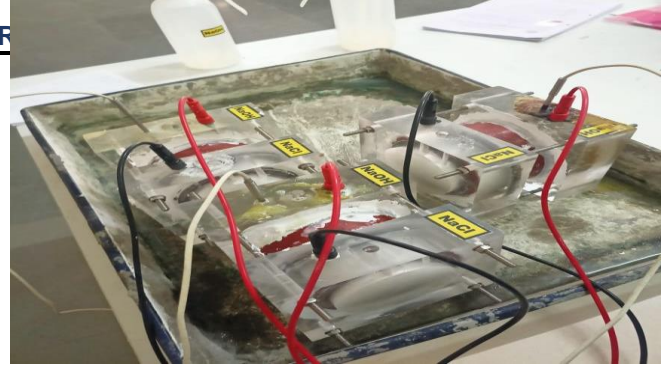
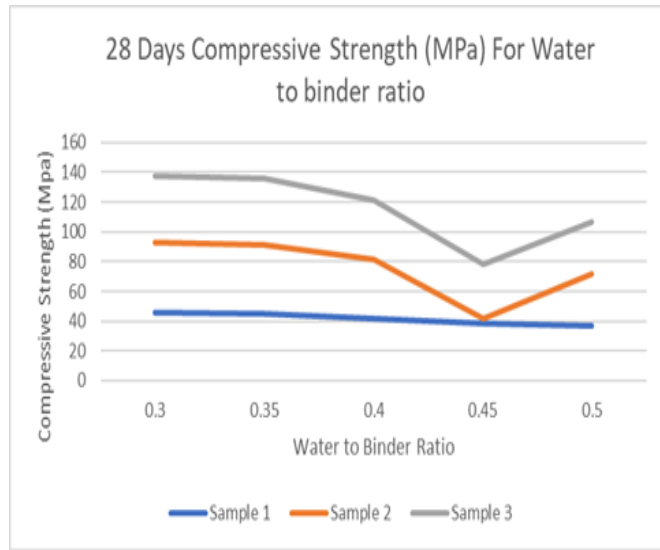


Fig no 4: RCPT cell connection

Table 4: RCPT test readings.

V	time (min)	C1 (mA)	C2 (mA)	C3 (mA)	Temp1 °C	Temp2 °C	Temp3°C
59	30	79.5	76.3	79.5	86.3	83.9	76.1
59	60	89	89.4	86.2	54.6	44.4	49.3
59	90	110.3	125.2	112.5	79.3	59.5	67.8
59	120	130.4	140.4	132.9	91.8	84.3	78.7
59	150	132.8	159.9	152	101	98.7	100.6
59	180	189.1	189.9	193.4	100.6	96.8	100.4
59	210	226.3	196.4	202.4	99.6	95.2	96.6
59	240	240.9	228.9	216.2	93.5	94.5	98.5
59	270	256.6	240.9	240.1	88.4	93.1	100.2
59	300	289.8	269.6	249.4	97.6	92.6	98.3
59	330	299.2	289.5	264.4	86.3	91.8	98
59	360	309.5	316.7	310.3	85	90	97.5



Graph no.3: 28 days Compressive strength (CS) of Geopolymer Concrete

2. RCPT (Rapid Chlorine Penetration Test) :Rapid Chloride Permeability Tester, or RCPT, is a commonly used abbreviation. There are several applications and quality control use for the rapid chloride permeability test. For the purpose of evaluating concrete samples (specimens) for the concrete ion permeability test for the civil engineering department and several research centers, RCPT provides multiport testing capabilities. RCPT is another name for the Coulomb test. In order to provide a quick estimate of the concrete's resistance to chloride ion penetration, this test method determines the electric conductivity of concrete. The RCPT approach, which is the fastest method, is frequently used for defining specifications and managing quality. The voltages accessible across the concrete specimen under evaluations are displayed on the digital led displays. There are two chambers in the diffusion. NaOH and NaCl solutions with a concentration of 0.3 m each are produced.



Graph no.4: Current passing through each cell

3. Acid Attack on Geopolymer concrete : Due to industrial activity and high concentrations of carbon dioxide, Sulphur dioxide, and nitrogen dioxide, acid showers are becoming a common occurrence. When they come into contact with rainwater, these produce the corresponding acids, including carbonic acid, sulphuric acid, and nitric acid. Acid rain weakens cement concrete, cement mortar, and corrodes steel in RCC when it falls on man-made structures because the acid in the rain neutralizes and corrodes calcium-based alkaline chemicals to generate soluble compounds. In essence, geopolymer concrete is an alkaline substance. The three-dimensional networks known as geopolymers are created when materials containing alumina and silica combine with alkaline liquids. The four-fold coordination of Al^{3+} in $(AlO_4)^-$ allows Na^+ in the alkaline activating solution to balance the excess negative charge. Due to the depolymerization and de-alumination of geopolymer gels, geopolymer concrete degrades.



Fig no.5: Immersion of cubes in acid

Table no.5: Weights and compressive strength after 15days

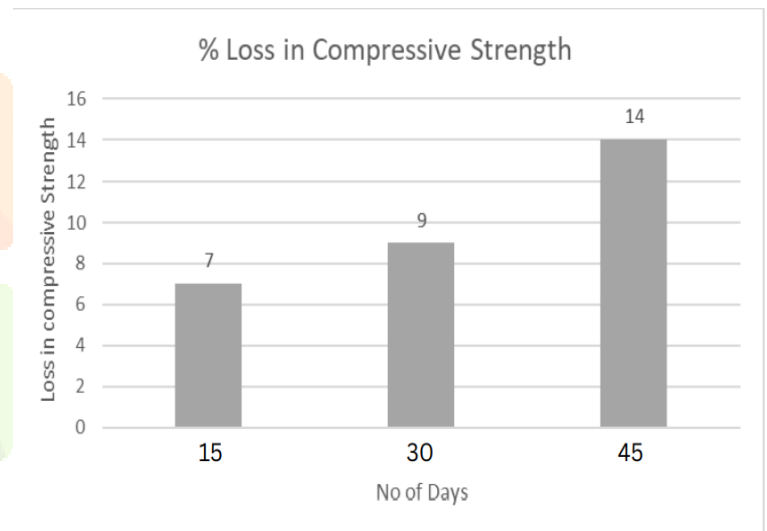
After 15 Days			
Cubes	Initial wt.	After wt.	CS
1	883	880.351	39.61
2	854	850.79	32.11
3	856	852.87	31.69

Table no.6: Weights and compressive strength after 30days

After 30 days			
Cubes	Initial wt.	After wt.	CS
1	850.5	843.687	41.39
2	861	856.6	33.89
3	740	737.192	30.18

Table no.7: Weights and compressive strength after 45days

After 45 days			
Cubes	Initial wt.	After wt.	CS
1	887	880.726	39.967
2	917	903.186	36.304
3	890	882.737	43.981



Graph no.5: % loss in compressive Strength

VII. CONCLUSIONS

- The material which was procured from Nashik and also from Pimpri were tested in the laboratory. And the resulted was used for design of geopolymer concrete.
- Out of the two-fly ash class F and class C. The fly ash to be used in the design is class F, because Compared to class C fly ash, class F fly ash is more efficient. As there are various grades of fly ash such as P10 to P100. The grade of fly ash to be use is P100.
- The ideal conditions for curing for fly ash-based mixes is temperature greater than 30 °C and less than 50 °C for 24 hours.
- The parameters were fixed in this study for the design of geopolymer concrete but the alkaline activator to fly ash ratio and different zones of sand were varied. By studying the strength of the

geopolymer concrete by varying different parameter, we got the result that 0.35 ratio gave good strength to the geopolymer concrete.

- By raising the solution/fly ash ratio, more water can be added to a given amount of fly ash to make geopolymer concrete more workable. Therefore, compared to solution/fly ash values of 0.30, 0.35, 0.40, or 0.45, 0.50 represents a more practical solution/fly ash value for GPC.
- For the same solution/fly ash ratio of 0.35, the grading of the fine aggregate and the amount of water have an impact on the compressive strength of geopolymer concrete. Zone 4 has sand that conforms more readily than zone 1's compressive strength.
- The RCPT apparatus test results shows that there is moderately penetration of chlorine ions into the geopolymer samples.
- In the acid attack test, there is successive decrease in the weight as it decreases about 0.3% to 0.6%. In the similar way there is decrease in the compressive strength which is about 7% to 14%.

VIII. ACKNOWLEDGEMENT

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IX. REFERENCES

- [1] Al Bakri Abdullah, M.M., Kamrudin, H., Ismail, K.N., Hussain, M., Zarina, Y. and Rafiza, A.R., 2012. Correlation between Na₂SiO₃/NaOH ratio and fly ash/alkaline activator ratio to the strength of geopolymer. In *Advanced materials research* (Vol. 341, pp. 189-193). Trans Tech Publications Ltd.
- [2] Aleem, M.A., Arumairaj, P.D. and Vairam, S., 2013. Chemical formulation of geopolymer concrete with m-sand. *Int J Res Civ Eng, Archi Des*, 1(2), pp.5460.
- [3] Assi, L.N., Deaver, E.E., ElBatanouny, M.K. and Ziehl, P., 2016. Investigation of early compressive strength of fly ash-based geopolymer concrete. *Construction and Building Materials*, 112, pp.807-815.
- [4] Bagchi, S.S., Ghuleand, S.V. and Jadhav, R.T., 2012. Fly ash fineness—Comparing residue on 45-micron sieve with Blaine's surface area. *Indian ConCreTe Journal*, p.40.
- [5] Fazli, H., Yan, D., Zhang, Y. and Zeng, Q., 2021. Effect of size of coarse aggregate on mechanical properties of metakaolin-based geopolymer concrete and ordinary concrete. *Materials*, 14(12), p.3316.
- [6] Al Bakri Abdullah, M.M., Kamarudin, H., Ismail, K.N., Bnhussain, M., Zarina, Y. and Rafiza, A.R., 2012.

Correlation between Na₂SiO₃/NaOH ratio and fly ash/alkaline activator ratio to the strength of geopolymer. In *Advanced materials research* (Vol. 341, pp. 189-193). Trans Tech Publications Ltd.

- [7] Guades, E.J., 2016. Experimental investigation of the compressive and tensile strengths of geopolymer mortar: The effect of sand/fly ash (S/FA) ratio. *Construction and Building Materials*, 127, pp.484-493.
- [8] Hassan, A., Arif, M. and Shariq, M., 2019. Use of geopolymer concrete for a cleaner and sustainable environment—A review of mechanical properties and microstructure. *Journal of cleaner production*, 223, pp.704-728.
- [9] Patankar, S.V., Ghugal, Y.M. and Jamkar, S.S., 2015. Mix design of fly ash based geopolymer concrete. In *Advances in structural engineering* (pp. 1619-1634). Springer, New Delhi.
- [10] Patankar, S.V., Jamkar, S.S. and Ghugal, Y.M., 2014. Effect of grading of fine aggregate on Flow and compressive strength of geopolymer concrete. In *UKEIRI concrete congress-innovations in concrete* (pp. 1163-1172).
- [11] IS Codes references
- [12] IS 456 (2000): Plain and Reinforced Concrete Code.
- [13] IS 1343 (2012): Reinforced Concrete and Prestressed Concrete Code.
- [14] Book references
- [15] Concrete Technology: Theory and Practice by M. S. Shetty.