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Effect of Varying Molarity and Temperature on Geopolymer Concrete

Riteeka S. Jadhav[1], Dr. U.R. Kawade[2], D.S.Patare[3]
[1,2,3]Dept. Of Civil Engineering, DVVP COE, Ahmednagar

***Abstract*—This project explores the influence of different molarities and temperatures on the mechanical and durability properties of geopolymer concrete (GPC). Through systematic studies and experimentation, it seeks to determine optimal conditions for producing GPC with improved performance and environmental sustainability, thereby enhancing its potential as an alternative to traditional concrete.**

***Index Terms*— curing temperature, durability, geopolymer concrete, normal concrete, strength**

I. INTRODUCTION

In the last two decades, significant research has focused on alternative binders like geopolymers and alkali-activated binders, often derived from industrial by-products rich in aluminosilicates such as fly ash, blast furnace slag, and silica fume. These materials exhibit cement-like properties when mixed with aqueous alkali solutions like NaOH, KOH, and Na2SiO3, promoting sustainable material use. In an alkaline environment, amorphous aluminosilicate compounds dissolve quickly, forming extensive networks of polymeric gels through condensation. Geopolymer concrete (GPC) is an environmentally friendly alternative to traditional concrete, using aluminosilicate waste materials like fly ash, blast-furnace slag, and metakaolin, activated by compounds like sodium hydroxide and sodium silicate. This initiates the geopolymerization process, forming a dense polymer structure. GPC offers versatile and sustainable construction solutions, benefiting environmental conservation, sustainable development, economic growth, and infrastructure quality and safety, ultimately improving society's overall well-being.

Effects of Curing Temperature on Geopolymer Concrete: The curing temperature significantly influences the development and performance of geopolymer concrete. Achieving the optimal curing temperature is essential for the desired properties, performance, and durability of geopolymer concrete. While higher temperatures can expedite strength development, they need to be regulated to prevent adverse effects like rapid drying, shrinkage, and decreased workability. Proper temperature management can result in a denser, stronger, and more durable geopolymer concrete with enhanced mechanical and chemical properties, ultimately enhancing the sustainability and long-term performance of concrete structures. The properties of geopolymer concrete, a sustainable alternative to traditional Portland cement concrete, are affected by curing conditions, including temperature.

II. LITERATURE REVIEW

Elsa Paul delved into the performance of various industrial by-products like fly ash (FA), copper slag (CS), and ground granulated blast furnace slag (GGBFS) in influencing the properties of geopolymer concrete (GPC). GGBFS presents a promising solution for addressing the heat-curing challenges associated with GPC. The inclusion of copper slag eliminates the need for superplasticizers and enhances workability. The feasibility of utilizing such waste materials was assessed through cost analysis.

Solomon Oyebisi et al. demonstrated that GGBFS-CCA-based geopolymer concrete showcases reduced environmental impact and superior sustainable and economic efficiency compared to Portland cement concrete. This finding underscores its potential for fostering a cleaner built environment and promoting sustainable construction practices.

Thakkar Sonal et al. explored the use of ambient curing techniques for geopolymer concrete. They utilized a blend of blast furnace slag and fly ash as source materials and opted for sodium hydroxide and silicate as activators due to their accessibility and costeffectiveness. This approach led to the development of M40 grade concrete, suggesting that sustainable materials can be effectively employed in prestressing applications without compromising on strength.

Mohamed Amin et al. employed industrial by-products such as fly ash, metakaolin, and granulated blast furnace slag as the foundation for high-strength geopolymer concrete (HSGC). SEM images revealed that the geopolymer matrix contained a greater dispersion of small-sized pores, suggesting significantly higher compressive strength compared to other experimental mixtures.

Ghasan Fahim Huseien et al. In their paper, examine the microstructural and mechanical characteristics of multi-blend geopolymer mortars (GPMs) in relation to solution molarity. They observe a linear decrease in flowability and setting time of GPMs with increasing alkali concentration. Conversely, comprehensive, split tensile, and flexural strengths, as well as density, are found to improve with higher alkali concentrations. GPMs activated with 12 M NH solution exhibit significant silica dissolution effects

Z. Podolsky conducted a review on the addition of waste materials with diverse chemical compositions and morphologies. The research findings indicate a lack of guidelines for the mix design of geopolymer concrete (GPC), resulting in significant variations in design parameters and, consequently, in strength and durability properties..

III. PROBLEM STATEMENT

Despite increasing interest in geopolymer concrete, comprehensive studies on the effects of varying molarity and temperature on its mechanical and durability properties are lacking. It's crucial to identify optimal conditions for producing high-performance and environmentally sustainable geopolymer concrete. This project aims to improve geopolymer concrete's performance as a viable alternative to conventional concrete by understanding the influence of various factors on its properties.

IV. AIMS AND OBJECTIVES

Aim:

1.To investigate the influence of different molarities on the properties of geopolymer concrete.

2.To examine the impact of varying temperatures on the performance and characteristics of geopolymer concrete.

3.To optimize the molarity and temperature conditions to enhance the mechanical and durability properties of geopolymer concrete.

Objectives:

•To prepare geopolymer concrete specimens with different molarities (viz. 12M, 14M 16M)

•To cure the geopolymer concrete specimens at varying temperatures (viz. 75ºC, 70ºC, 65ºC)

•To determine the workability of the geopolymer concrete mixtures using slump and flow tests.

•To evaluate the compressive strength, tensile strength, and flexural strength of the geopolymer concrete specimens.

V. MATERIALS AND METHODOLOGY

This section delineates the process of developing GGBS-based geopolymer concrete, considering different molarities, alkaline solution ratios ($Na_2SiO_3/NaOH$), and various temperatures.

The main ingredients of geopolymer concrete are as follows,

1.Fly ash 2.GGBS 3.Alkaline solution 4.Fine aggregate 5.Coarse aggregate.

Ground granulated blast slag- Ground granulated blast slag (GGBS) is commonly derived as a by-product from blast furnaces in metal production processes. The molten slag consists of approximately 30–40% silicon dioxide and 40% calcium oxide, similar in chemical composition to ordinary Portland cement (OPC). This residual slag, which floats atop the molten iron during the iron ore reduction process, is often tapped off as a molten liquid and rapidly quenched with copious amounts of water to produce GGBS.

In the present study, GGBS obtained from JSW Cement Ltd. serves as the binding material.

Alkaline Solution-

The NaOH solution was prepared by dissolving either flakes or pellets in water. The mass of NaOH solids in the solution varied with the concentration, expressed in molarity (M). For instance, an 8M NaOH solution contained 320 grams of NaOH solids per liter (8 x 40 = 320, where 40 is NaOH's molecular weight). The NaOH solid masses per kg of solution for different concentrations were: 8M: 262g, 10M: 314g, 12M: 361g, 14M: 404g, and 16M: 444g. It's essential to recognize that NaOH solids constituted only a portion of the total solution mass, with water being the main component.

The sodium silicate solution's chemical composition comprised Na2O content between 14.05% and 16.05%, SiO2 content between 32.14% and 34.01%, and water content between 50.93% and 52.92% by mass. The solution had a specific gravity of 1.53 g/cc and a viscosity of 400 cp at 20°C. The sodium silicate to sodium hydroxide ratio was maintained at 2, 2.5, and 3. Table 01 presents the chemical composition of 97% NaOH, while Table 02 details the sodium silicate solution with different mix proportions.

Table 01 Chemical composition of sodium hydroxide.

Chemical component	**Percentage (%)**
Sodium hydroxide (min.)	97
Carbonate	2
Chloride	0.01
Sulphate	0.05
Potassium	0.1
Silicate	0.05
Zinc	0.02

Table 02. Chemical composition of sodium silicate (Na2SiO3)

Na2O	SiO2	Water Content	Total Solids
14-16 %	32-34 %	48-52 %	48-52%

Mix Design for M40 grade of Geopolymer Concrete

Using Proposed Method by Prof. S.V. Patankar, a sample mix proportioning for M40 grade of geopolymer concrete is carried out using proposed method.

Table 03. Ingredients and proportion for Geopolymer concrete

Table 04. Representing the specimen schedule and curing temperature

Thus for each set of cured temperature range geopolymer concrete is tested for strength and flexure. Thus the effect of curing on strength of concrete is measured.

Ingredients of Geopolymer	Fly Ash	NaOH	Na2SiO3	Sand	C.A.	Total Water	Extra Water
Quantity (Kg/m3)	500	58.33	116.66	614.09	1186.77	110	14.14
Proportion	1	0.35		1.228	2.373	0.22	0.028

VI. RESULT AND DISCUSSION

Trial	Molarity of NaOH	Ratio of Na2SiO3/NaOH	Curing temperature
1	12 M	2	75°C
			70°C
			65°C
2	14M	2	75°C
			70°C
			65°C
3	16 M	2	75°C
			70°C
			65°C
4	12 M	2.5	75°C
			70°C
			65°C
5	14 M	2.5	75°C
			70°C
			65°C
6	16 M	2.5	75°C
			70°C
			65°C
7	12 M	3.0	75°C
			70°C
			65°C
8	14M	3.0	75°C
			70°C
			65°C
9	16M	3.0	75°C
			70°C
			65°C

In this section it has been tried to explore the results drawn from the research made in this particular work. This is a thorough display of all the data that was gathered and painstakingly examined to identify trends, patterns, and noteworthy findings.

Results of Workability of Geopolymer concrete

Table.05. Workability result for alkaline ratio of 2.0

Particulars	Mix grade	Ratio Of Na2SiO3 / NaOH	Slump test (mm)	Average Slump (mm)	Flow test (mm)	Average Flow (mm)
GPC 12M	M40	2	119	115.67	151	147
			111		149	
			117		141	
GPC 14M			113	105.67	134	128
			101		128	
			103		122	
GPC 16M			97	90.33	115	109.33
			89		108	
			85		105	

Table.06. Workability result for alkaline ratio of 2.5

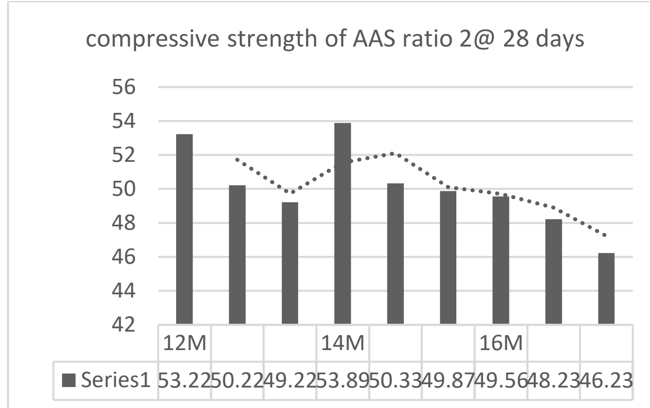
Particulars	Mix grade	Ratio Of Na2SiO3 / NaOH	Slump test (mm)	Average Slump (mm)	Flow test (mm)	Average Flow (mm)
GPC 12M	M40	2.5	106	105.33	139	126.33
			109		121	
			101		119	
GPC 14M			102	98.33	117	109
			98		107	
			95		103	
GPC 16M			99	92.67	104	102.67
			94		103	
			85		101	

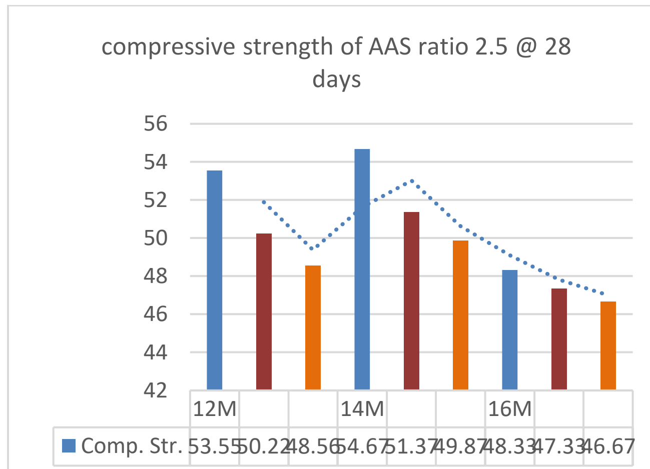
Table.06. Workability result for alkaline ratio of 3.0

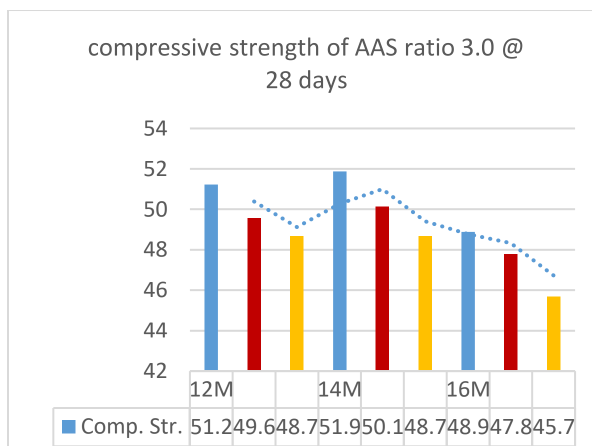
Particulars	Mix grade	Ratio Of Na2SiO3/ NaOH	Slump test (mm)	Average Slump (mm)	Flow test (mm)	Average Flow (mm)
GPC 12M	M40	3.0	115	113	124	119
			111		119	
			113		114	
GPC 14M			109	104.67	115	109.33
			102		109	
			103		104	
GPC 16M			97	91.33	100	95
			93		95	
			84		90	

Results of strength, STS and Flexure test

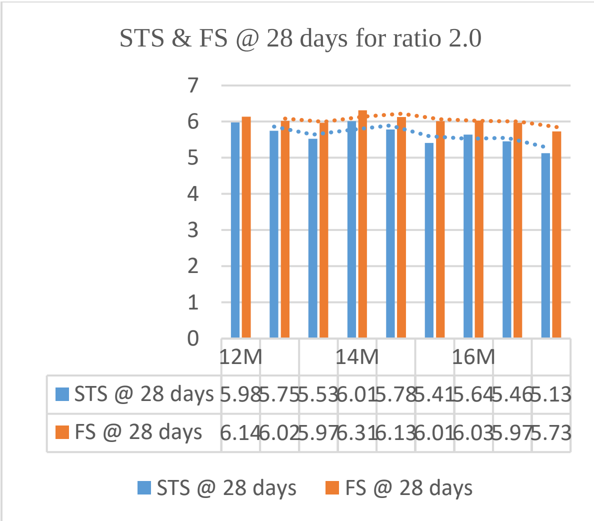
a. Strength test

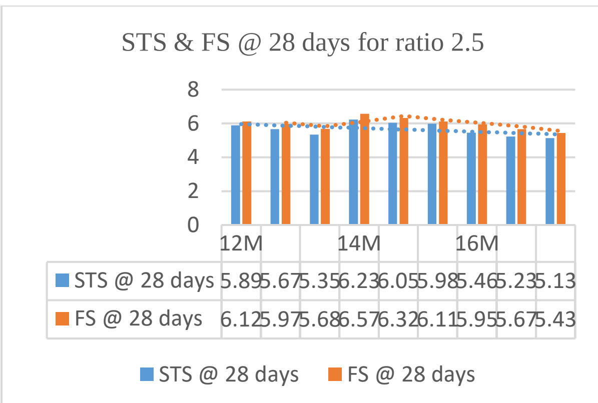


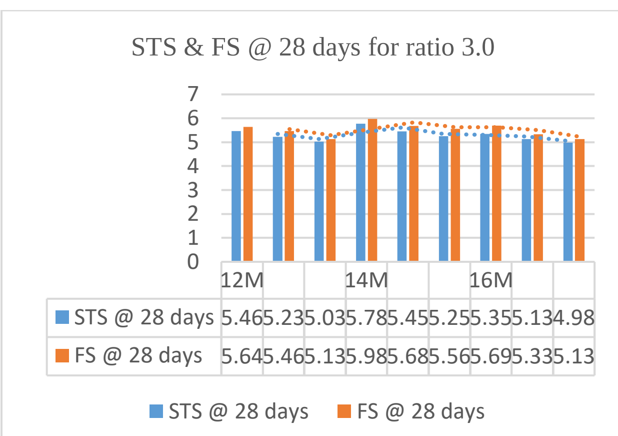




b. STS and Flexure test results:







VII. CONCLUSION

In this study, the performance of Geopolymer Concrete (GPC) incorporating Ground Granulated Blast Furnace Slag (GGBS) as a replacement for Portland cement was comprehensively evaluated under varying curing temperatures. The incorporation of GGBS in Geopolymer Concrete presents a promising alternative to traditional Portland cement-based concrete, especially when subjected to optimal curing temperatures. It offers a viable solution to address sustainability concerns in the construction industry without compromising on performance.

Optimal Curing Temperature: The mechanical properties of GGBS-based GPC were notably affected by curing temperature, with an optimal range between 65ºC and 75ºC yielding the highest compressive strength and durability. As the AAS ratio increased from 2.0 to 3.0, workability decreased. Flow table and slump cone tests showed that higher molar concentrations and alkaline ratios stiffened the matrix, making it less manageable; thus, the use of admixture is recommended.

Strength Development: GPC specimens cured at higher temperatures showed accelerated early-age strength development compared to those at ambient temperatures. However, excessive heat reduced ultimate strength due to thermal stress-induced microcracks. While higher temperatures enhanced compressive, split tensile, and flexural strength, lower temperatures slightly reduced strength but remained within an acceptable range. The maximum compressive strength of 54.67 N/mm2 was achieved at an AAS ratio of 2.5 with a 14M concentration.

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