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***Abstract*— Cement is essential in global building, notably contributing to infrastructure development and impacting economies. However, its manufacturing necessitates the use of significant raw resources such as limestone, resulting in CO_2 emissions and contributing to global warming. Current research in this sector is mostly focused on developing ecologically friendly solutions. In the study, a geopolymer binder is considered as a substitute for the traditional cement binder, offering comparable effectiveness. This document explains how to make Geopolymer concrete was created by eliminating Portland cement and instead activating industrial byproducts such as Fly ash, Ground granulated blast furnace slag, Metakaolin and silica fume. Local standard quartz sand size 300 µm, and brass coated steel fibers with diameters of 0.28 mm and lengths of 13 mm were used in the concrete mix. The fresh characteristics slump value and mechanical properties (compressive strength) of the resulting geopolymer concrete were evaluated when cured at 60 ºC and 100 ºC temperature for 24 hours and after that cured at ambient temperature for 7 and 28 days. The study included 12 molar concentrations of NaOH. The Geopolymer Concrete with steel fibers achieved the highest average compressive strengths, reaching 59.24 N/mm^2 with 2% of 13 mm length fibers in hand mix at 12 M concentration. The compressive strengths observed in this investigation are equivalent to high strength previously reported in the literature. Using industrial by-products and diverging from traditional curing procedures for geopolymer concrete production will improve sustainability and allow for cast-in-situ geopolymer applications.**

Keywords*— *Geopolymer concrete, Sodium hydroxide pellets, Sodium Silicate solution, Compressive Strength.

I. INTRODUCTION

In recent years, global cement production has increased dramatically. Following fossil fuels and changes in land use, it stands as the third most significant contributor to human-caused carbon dioxide emissions [1]. In the future, the building industry will have to deal with the use of substitute materials, such as industrial wastes in place of cement [2]. "Joseph Davidovits" discovered a new kind of inorganic substance in 1972: Geopolymer binder or resin. One of the primary objectives for the development of geopolymers is to use industrial waste and to reduce greenhouse gas emissions from cement manufacture. Geopolymer concrete, which relies on inorganic materials, demonstrates similarity to traditional concrete. However, it requires the presence of abundant silica and alumina, such as those found in fly ash, silica fume, ground granulated blast furnace slag (GGBFS), and soluble solutions like sodium or potassium [3,4]. Geopolymer concrete comprises two main elements: alkaline liquids and source materials. The creation of geopolymer binders results from the activation of industrial by-products through alkaline processes [3]. The replacement of byproduct materials for cement in the manufacture of geopolymer concrete minimizes CO_2 emissions into the environment [5]. Geopolymer concrete typically has exceptional compressive strength, limited longevity, and low flexural quality, which may limit its use in auxiliary projects [6]. Several factors impact the mechanical and long-term resilience of geopolymer concrete, including the fineness of fly ash and GGBFS, the molarities of NaOH solution, and the curing conditions, which involve exposure to sunlight and oven treatment [5, 6]. The mechanical properties of sodium hydroxide solution grow as the molarities increase. In general, up to 14 M sodium hydroxide solution is cost effective and has been shown to improve the durability of geopolymer concrete [7]. Alumino-silicate material (ASM), possessing minute particle dimensions akin to Portland Cement, functions as a supplier of silicate and aluminum. These components undergo a reaction in the presence of an alkaline solution. Typical alumino-silicate materials used in geopolymerization

encompass GGBS, fly ash, and metakaolin [8, 9]. To complete the geopolymerization process, activation necessitates the use of high-alkali substances such as sodium hydroxide and sodium silicate. When introduced to the alkaline solution, alkali-activated materials (ASMs) dissolve, initiating the formation process within geopolymer technology. This involves the recurrence of geopolymeric Si-O-Al-O interactions in an unstructured manner. The main outcomes of this reaction in geopolymer concrete are the development of C(N)-A-S-H gels, comprising a three-dimensional amorphous alumino-silicate network [10, 11]. In contrast to the C-S-H gel, the primary outcome of Portland Cement Concrete, this product has distinct properties. Furthermore, as compared to Portland cement concrete, geopolymer shown comparable/improved mechanical capabilities as well as greater durability qualities [12, 13].

In comparison to Portland Cement Concrete, Geopolymer Concrete may be evolved to have better qualities, such as greater acid and sulfate resistance and enhanced temperature resistance, abrasion resistance, and better strength [13, 14]. Rovnank [15] explored how varying the curing temperature and duration impacts dense GPC. The findings revealed that higher curing temperatures accelerate the geopolymerization process, leading to enhanced early strength. Hassan and colleagues [16] experimented with room temperature curing for Geopolymer concrete but found it to be impractical. Consequently, the manufacturing of Geopolymer concrete necessitates heat curing. The geopolymerization process is impeded at low curing temperatures, leading to diminished mechanical properties of geopolymer concrete.

The main goal of this research is to examine how the compressive strength of geopolymer concrete is affected by varying the molarity of 12M sodium hydroxide and the curing temperatures. This investigation is based on the binder compositions of fly ash, GGBS, Metakaolin, and Silica Fume. Additionally, brass-coated steel fiber is incorporated to enhance compressive strength and corrosive resistance. The curing process involves exposing the concrete to hot oven air at temperatures of 60°C and 100°C for 24 hours, followed by further curing at room temperature for 7 and 28 days. This specific curing method significantly improves the strength of the concrete. The selection of industrial waste as a component in the geopolymer concrete mixture, serving as an alumino-silicate material, activated with an alkaline activator solution of sodium silicate and sodium hydroxide, is a distinctive aspect of this research.

II. EXPERIMENTAL WORK

A. Materials

Class F Fly ash with a reduced calcium content that adheres to the specifications outlined in IS 3812-2003 [17] and GGBS confirming IS 16714:2018 [18] with specific gravities of 2.00 and 2.87 were obtained from Suyog Elements PVT LTD in Baruch, Gujarat, India. The specific gravity of the silica fume, which comes from Astra Chemicals in Chennai, Tamil Nadu, India, is 2.64. The specific gravity of the metakaolin, which comes from AJ Corporation in Mumbai, India, is 2.6. Table 1 presents the chemical makeup of the binder material employed in the research investigation.

TABLE I. Chemical Composition of Fly ash, GGBS, Metakaolin and Silica Fume (w%)

Property	***Fly ash***	***Slag***	***Metakaolin***	***Silica Fume***
SiO_2	30.53	34	51	99.92
Al_2O_3	30.53	17.4	45	0.031
CaO	-	33.34	0.02	0.00
MgO	1.4	8.76	0.07	0.00
Fe_2O_3	30.53	1.96	0.35	0.012
Na_2O	0.46	-	0.1 3	0.004
CL	0.029	0.029	-	-
SO_3	0.64	0.024	-	-
LOI	0.96	0.46	0.50	0.001

This study utilized commercially accessible pellets of sodium hydroxide (NaOH) with a 98% purity. Additionally, commercially available liquid sodium silicate (Na_2SiO_3) which is also called Waterglass was employed, and its chemical composition is detailed in Table 2.

TABLE II. Properties of Sodium silicate gel

Materials	***Chemical compositions (wt/wt)***			***Specific gravity***
Na_2SiO_3	Na_2O	SiO_2	H_2O	1.67
	16.25%	33%	50.75%	

Fine aggregate sourced from the local river of Vadodara, Gujarat, meeting the specifications of zone II according to IS 383-2016 [19], with a maximum size of 300 µm and specific gravity and fineness modulus values of 2.63 and 3.6, respectively, has been utilized as the fine aggregate (FA).

Distilled water is employed in the process of blending with sodium hydroxide (NaOH). This purified water is crucial for ensuring the accuracy and effectiveness of the sodium hydroxide mixture. The use of distilled water in this context is essential to maintain the quality and reliability of the resulting solution.

A special type of fiber with extraordinary strength and durability called brass coated micro steel fiber confirming the specification ASTM A-820 Type-1 [20] is utilized of size 0.28 mm diameter and 13 mm length with straight-in-shape in this experimental work. Table 3 presents the specifications of the steel fiber outlined below.

Table III. Characteristics of Brass-Coated Micro Steel Fibers

TEST	*SPECIFICATION NO. ASTM A-820 TYPE - 1*	*RESULTS*
Carbon	1.00%	0.71%
Silicon	0.30%	0.20%
Manganese	1.20%	0.53%
Sulphur	0.03%	0.005%
Phosphorous	0.03%	0.021%
Tensile strength of wire	2750-3050MPa	2815-3018

Conplast SP550 is a water-reducing additive with a wide variety of applications for microsilica concrete and it meets IS: 9103:1999(2007) and ASTM-C-494 Type 'G' standards [21, 22]. It is a brown liquid that is instantly dispersible in water and is based on Sulphonated Naphthalene Super plasticizer used in this study. Table 4 displays the outlined specifications of the conplast 550SP as presented below.

Table IV. Specifications of the Conplast 550SP.

Specific gravity	1.23 ± .02
pH at 27^0 C	Minimum 6*
Chloride content	Nil to IS:456*

B. Mixing, Casting and Curing

Considerable heat is produced when alkali activator solutions (AAS's) are blended. It is advised to allow the solution to reach room temperature before blending it with the dry ingredients [23]. Previous studies [24,25] proposed a method wherein alkaline solutions are directly mixed with dry alumino-silicate materials (ASM's) instead of the conventional pre-mixing approach. In this particular experiment, the alkaline solution was prepared 24 hours in advance before being mixed with the dry materials. The activation of the binders involved the use of 12 molar concentrations of NaOH combined with Na_2SiO_3 to produce the solution of alkali activators. The ratio of sodium silicate to NaOH was set at 1:1, and the alkaline liquid to binder ratio was maintained at 0.41 after the number of trials. The sodium hydroxide (NaOH) pellets, when mixed with distille water, were allowed to sit at room temperature for 24 hours to minimize excessive heat production. To achieve consistency, Geopolymer Concrete (GPC) mixtures are crafted using a blend of specific raw materials, namely fly ash, GBFS, silica fume, and metakaolin. The production of GPC involves the utilization of an alkaline activator, which is created from sodium silicate (Na_2SiO_3), sodium hydroxide (NaOH), and water that has been allowed to naturally cool to room temperature for a day before being employed in the GPC manufacturing process. To start, the binders (including fly ash, GBFS, metakaolin, and silica fume) were blended together in a dry mixture using manual mixing for 10 minutes before adding silica sand and blending for another 5 minutes. Then adding steel fiber mix for another 3 minutes. Ultimately, combine the alkaline liquid with the Naphthalene-based super plasticizer solution, gradually incorporating it into the dry mix and ensuring thorough mixing for a duration of 4 to 5 minutes. Following this comprehensive blending, the workability of the fresh geopolymer concrete was assessed using a slump test. Subsequently, the freshly mixed geopolymer concrete was cast to create cube specimens measuring 150x150x150 mm, to study the compressive strength of geopolymer concrete, respectively. Every cast specimen in the mold was given a 24-hour resting time. Afterwards, the specimens were taken out of the mold and allowed to cure for 24 hours at 60 and 100 degrees Celsius in an oven. After subjecting the geopolymer concrete cubes to 24 hours of oven curing, they were subsequently placed at room temperature for the required number of days before conducting compression tests to obtain results.

Table 5 summarizes the details of the mix proportion of binders in percentages. The three different mix designations M1, M2 and M3 has 12 molar concentrations mix. Total 36 numbers of cubes were casted for this experimental work shown in figure 1. For each mix proportion, 12 examples were cast for each mix and cured for 24 hours at 60 and 100 degrees Celsius, respectively shown in figure 2. The samples were subsequently removed from the oven and allowed to undergo curing at ambient temperature (27 ± 2 °C) for 7 and 28 days before being tested shown in figure 3. Figure 4 shows the compression test of cube specimens, which are the average of three measurements, with a load capacity of 2000 KN. Table 6 provides a summary of the mix proportion details for binders, expressed in kilograms per cubic meter (kg/m^3).

TABLE V. The parameters of mix proportions for compression strength development.

Parameters	*(%) of ASM*			
	Fly ash	*GGBS*	*Metakaolin*	*Silica fume*
M1 (mix)	20%	40%	10%	28%
M2 (mix)	10%	60%	10%	18%
M3 (mix)	15%	53%	10%	20%
Super plasticizer (%)	1.2%			
Steel Fibers (%)	2%			
Na_2SiO_3/NaOH Ratio	1			
Alkaline Solution to Binder Ratio	0.41			
Curing temperature	60°C and 100°C			
NaOH Molarity	12			

TABLE VI. The parameters of mix proportions for details for binders, in kilograms per cubic meter (kg/m3).

S.No	*Materials*	*Weight in (Kg/m^3)*
1.	Fly ash	174
2.	Ground Granulated Blast Furnace Slag (GGBS)	435
3.	Metakaolin	87
4.	Silica Fume	148
5.	Fine Aggregate	1249
6.	Steel Fiber	26
7.	superplasticizer	13.07
8.	Water	206
9.	Sodium Hydroxide (NaOH)	55
10.	Sodium Silicate (Na_2SiO_3)	12381

(a) Compacting concrete (b) Casted cubes

Fig.1. Geopolymer Concrete Cube: A Casting Specimen.

(a) (b)

Fig.2. Specimen Cubes Subjected to Curing at different temperature (a) 60 °C and (b) 100 °C in an Oven.

Fig. 3. Specimen Successfully Cured at Ambient Temperature.

Fig. 4. Cube Specimen Compression Testing

C. Preperation of alkaline liquid

1) Sodium Hydroxide

Dissolve sodium hydroxide pellets in water at 12 M concentration, prepare solution 24 hours' prior, use within 36 hours to prevent semi-solid transformation.

2) Molarity Calculation

A sodium hydroxide (NaOH) solution at 12 molar contains 12 x 40 = 480 grams of NaOH per liter due to its molecular weight (40). Water remains the primary component in alkaline solutions.

D. Test procedure

Slump testing was used to determine whether Geopolymer concrete was workable in accordance with IS 1199-1959 [26]. According to IS 516-1959, the strength test of Geopolymer concrete cubes was carried out [27]. The treated cubic samples were subsequently placed into the compression testing apparatus as per the codal requirements. The outcomes of the tests have been visually depicted. The test results have been graphically represented.

III. RESULTS AND DISCUSSION

Fresh mixes of geopolymer concrete were observed to possess a high level of viscosity and cohesion, accompanied by a medium to high slump. The workability of the geopolymer concrete diminishes as the initial condition when mixing through hand because of high concrete grade, primarily due to a decrease in the alkaline-to-geopolymer solids ratio as per mix design but after adding extra alkaline liquid and making it to workable concrete at 0.41 alkaline solution/binder (As/b) ratio. Therefore, increase in the alkaline activator solution (AAS's) ratio enhances the slump value for any grade of geopolymer concrete, as a larger amount of sodium silicate and NaOH with water is added into the mixture during hand mixing through. Consequently, an elevated concentration of AAS's reduces the flow of geopolymer concrete. Therefore, in hand mixing it can be concluded that as the higher grade concrete, the mixture becomes more rigid and difficult to mix, leading to a decrease in workability and ultimately resulting in a reduction in strength.

The study aimed to investigate the compressive strength of Geopolymer concrete by varying the binder content. Specifically, the research examined the range of 10% to 20% for fly ash, 40% to 60% for GGBS, and a constant 10% of metakaolin for all mixtures. Additionally, 18% to 28% of silica fume was included in the investigation, focusing on dry heat curing in an oven at elevated temperatures of 60°C and 100°C. The study considered three different mix proportions at 12 molar concentrations.

After 7 days, the findings indicated that, among the three different mix proportions, the M1 mixture with a 12 molar concentration exhibited the highest strength, reaching approximately 54.87 N/mm². Similarly, at the 28-day mark, the results indicated that the M2 mix with the same 12M molar concentration achieved a maximum strength of 59.24 N/mm². These mixtures were initially cured at 100°C and then underwent room temperature curing for the remaining days during the preparation of hand-mixed geopolymer concrete. Figures 5 display the results of compressive strength tests for concrete cured for 7 days, covering three distinct mix proportions at 12 molars. The corresponding figures are provided below.

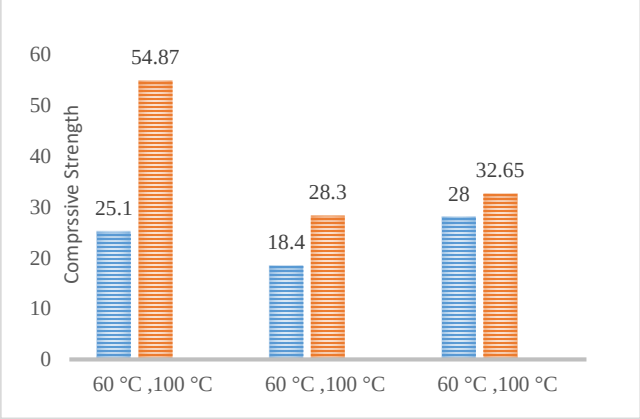

Fig. 5. Compressive Strength of Concrete at 7 Days for Mixes M1, M2, and M3 with a 12 Molar Concentration.

Figures 6 depict 28-day concrete compressive strength tests with varied proportions

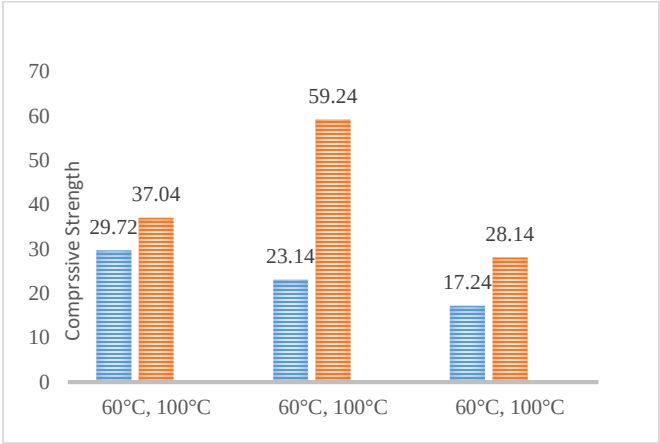

Fig. 6. Compressive Strength of Concrete at 28 Days for Mixes M1, M2, and M3 with a 12 Molar Concentration.

At a curing temperature set to 60°C, the M3 blend ratios, with a molarity of 12, yielded an optimal compressive strength of 28 N/mm² within 7 days. Similarly, for the M1 mix with a 12 molar concentration attained the highest compressive strength of 29.72 N/mm² after 28 days. Conversely, the M2 mix with the same molarity (12 Molar) exhibited the lowest result, registering a compressive strength of 18.4 N/mm after 7 days. Additionally, for the M3 mix with a molarity of 12, the lowest compressive strength recorded was 17.24 N/mm² after 28 days. The marginal decrease in the compressive strength of geopolymer concrete could be linked to an increased concentration of alkali, which hampers the creation of silicate species. This decrease may be attributed to an excess of alkali content [29].

IV. CONCLUSIONS

This research carried out experiments to evaluate the compressive strength of geopolymer concrete by altering NaOH molarities, binder types, and curing temperatures. As a result, the discovered outcomes can be summarized concisely as:

- The higher the curing temperature, the greater the strength development.
- The compressive strength of geopolymer concrete rises as the curing temperature increases. Where observed that at 100 °C for 12M of M1 mix proportions strength has optimum in 7 days.
- The compressive strength of hand-mixed geopolymer concrete demonstrated an increase after 28 days in the M2 mix. To achieve better results, it is recommended to utilize a mixing machine for the mixture.
- When using different binder mix proportions while keeping the NaOH molarity constant, fluctuations in compressive strength have been observed.
- It is suggested that additional investigation is required to explore the long-term resilience of the mechanical characteristics in geopolymer concrete. Specifically, more research is needed on the constant ratio of Na_2SiO_3 to NaOH,

as this aspect of one-part geopolymer concrete warrants further study. Investigations of this nature have the potential to unveil the relationship between the initial compressive strength of geopolymer concrete and the activation of alumino-silicate through alkaline processes.

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