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Effect of Alkali Activator Ratio on Mechanical Properties of GGBS based Geopolymer Concrete

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Abstract: ***Geopolymer concrete also referred to as "green" and "environmentally friendly" concrete is carbon free binding material which can be ultimate replacement for traditional Ordinary Portland cement (OPC) concrete. OPC production is solely responsible for seven percentage (7%) of carbon dioxide (CO_2) gas emission globally. Taken in account, the serious threats imposed by ordinary Portland cement in coming future with its increasing use in construction projects, ecofriendly geopolymer concrete which aren't harassing to surroundings will be a boon in Civil engineering field. Here, in this paper we studied the behavior of Geopolymer Concrete using (GGBS) under the effect of varying concentration of Alkali Activators. The alkali activators Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) with Alkali Activator ratio (AAR) of 1:1.5, 1:2 & 1:2.5 were used. Also, the molarity of NaOH was altered for 8Molar, 10Molar and 12Molar. The specimens were casted for Compressive, Split Tensile and Flexural test and were tested after 7 days and 28 days of ambient curing. It was observed that Compressive, Split Tensile and Flexural strength of the GPC specimen increased with increasing molarity of Sodium Hydroxide (NaOH) and with increase in Alkali Activator Ratio.***

Index Terms: Alkali activator, GGBS, Compressive Strength, Flexural Strength, Split Tensile Strength, Molarity, Ambient Curing

I. INTRODUCTION

Cement is used excessively as a construction material all throughout the world ranking only second after water. Ordinary Portland Cement (OPC) is used as binding material to produce the concrete; hence it plays an important role in construction industries. Considering the rapid construction development all over the world it is for sure the demand of concrete will raise significantly [1]. But at the same time, it is much known that the production of OPC is not only utilize a lot of natural resources but also solely accounts for about 7% of the global carbon dioxide (CO_2) emission i.e. around 2.7 billion tons of greenhouse gases emissions yearly [1,4]. It is estimated that manufacturing of 1 tons of (ordinary Portland cement) OPC releases 1 tons of carbon dioxide.

Considering these serious threats which are sure to grow in coming future with advancement of construction industries, need of an alternative binder with less carbon footprint to replace environmental harassing cement is of prime importance.

In 1998, Davidovits proposed a geopolymer technology as an replacement to the Ordinary Portland Cement binder traditionally being used in construction industry [4]. Geopolymer are chain or networks of mineral molecules which are connected to each other by co-valent bonds. In this technology, the original material is rich in Silicon (Si) and Aluminum (Al) it reacts with high alkali solutions to produce binder material through the process of geopolymerisation. The alkaline solution act as activator for the polymerization process under high alkali condition on Si-Al mineral resulting into complex polymeric chain of Si-O-Al-O bonds [8]. The main significance of geopolymer technology is its ability to produce high performance binder from materials such as fly ash or GGBS.

Geopolymer concrete is the ultimate of the reaction of aluminosilicate containing materials with concentrated alkali solutions it produces an inorganic polymer binder. Though it had a past history starting in the 1940's and has attracted a significant number of researches, it has not yet been used significantly in mainstream concrete construction. However, in case of ready mixed applications usage of Geopolymer concrete in is increasing, also its application in the field of precast industry using accelerated curing is noticeable.

Geopolymer Concrete, in today world is emerges as a new environmental friend construction material for sustainable develops as there are a number of benefits associated with it. Geopolymer concrete not only reduces the CO_2 releases from the production of OPC but also effectively utilizes industrial wastage by product such as fly ash, blast furnace slag etc. as a original material which is activated by alkali solutions to act as a binder. CO_2 emissions to the atmosphere causes to cement and aggregates industry can be reducing about 79.95% with help of geopolymer technology [5]. Hence it can be said that the geopolymer concrete show consider promises to the applications in concrete industry as an alternative binder to OPC and is relatively new area for research that can lead us to mainstream use of geopolymer, environmentally friendly concrete eventually.

Prakash R. Vora et al. [1]

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performed experimental work in which they casted 20 geopolymer concrete mixes and evaluated the effect of various parameters in its compressive strength in order to enhance its overall performance. The results showed increase in compressive strength with increases in curing temperature, rest period, concentration of NaOH and decreases with increase in the ratio of water to geopolymer solids.

Wasan Ismail Khalil et al. [2] studied the mechanical properties and thermal conductivity of LWGPC. The replacement of natural light weight fine aggregate by 25% to 100% artificial fine lightweight aggregate leads to a decrease in compressive strength relative to the reference LWGPC at 28 days.

Maria Rajesh Antonyamaladhas et al. [3] studied and evaluated the behavior of GGBS and also the ANSYS analysis carried out. The casted GPC specimens were cured at 60^{o} C temperature for 24 hours and tested was performed after 1, 7, 14, 28 days of ambient curing. The best strength value was obtained on 40% replacement and 12M. From the, compressive, split-tensile, and flexural strength of GPC specimens were 20%, 43%, and 53% higher than those of the control specimens. Also, it was found that the experimental test results were approximately equal to the ANSYS.

R. Thenmozhi et al. [4] conducted an experimental study on Light weight aggregate based Geopolymer concrete. The coarse aggregate is partially replaced with pumice stone with various proportions like 0%, 10%, 20%, 30%, 40%, 50% with 8M NaOH. The casted specimen was tested for compressive, tensile and flexural strength. It was obtained that increase of pumice stone reduces the density and strength gently decreases.

Raijiwala D.B. et al. [5] evaluated the performance of fly ash based geopolymer concrete. ASTM Class F fly ash obtained from coal burning power station was used for binder. 8M, 10M, 12M, 14M, 16M of NaOH specimen were tested. Compressive Strength of GPC found to be increased by 1.5 times than of controlled concrete (M-25 achieves M-45). Similarly, Tensile strength increased by 1.45 and flexural strength increased by 1.5 times.Ramkumar et al. [6] performed an experimental study on GPC mixes of GGBS and fly ash 50% each. The mix was added with stainless steel fiber and mild steel fiber. The results showed increase of 20% in compressive strength than control mix. GPC along with added stainless-steel fibers is 57% higher than the control mix and GPC mix with added mild steel fibers is 75% higher than the control mix in terms of split tensile strength. Flexural Strength of GPC with added fibers is 24% more than control mix.Albitar et al. [9] presented a study on the behavior of geopolymer concrete in its wet and hardened states using class F fly ash. This paper mainly focused on the fact that green, eco-friendly geopolymer concrete can be a replacement for Ordinary Portland Cement (OPC).

B. Sarath Chandra Kumar et al. [10] evaluated the Compressive and Split Tensile strength in laboratory and Regression analysis performed by using R Software to find correlation between Compressive and Split tensile for various mixes of Geopolymer concrete.

M. Ratna Srinivas et al. [11] examined the flexural behavior of GPC beams at different molarity of NaOH while fix AAR 1:2.5. The ultimate load, cracking load and the load Vs deflection graphs were plotted and the experimental results compared with conventional RC beam of M40 grade. It was concluded that GGBS based GPC showed greater performance than that of conventional OPC.

II. EXPERIMENTAL SETUP

A. MATERIAL

The major ingredients for casting the geopolymer concrete are Ground granulated blast furnace slag (GGBS), Fine aggregate, Coarse aggregate, Alkaline solution. These ingredients were tested for the properties according to the Indian standard codes. GGBS was tested as per IS: 12269-1987, Aggregate were tested as per IS: 1786-1970.

GGBS GGBS is the by-product from the blast-furnaces used to make iron. It is one of the best examples for the alternative binder for cement in concrete. It is the most economical than the conventional binder.

Table I. Chemical Composition of GGBS

Chemical Compound	Percentage
Calcium oxide	40 %
Silica	35 %
Alumina	13%
Magnesia	8%

Table II. Physical Properties of GGBS

Colour	Off-White
Sp. Gravity	2.9
Bulk Density	100-1100 kg/m3 (Loose) 1200-1300kg/m3 (Vibrated)

Fine Aggregate

Fine aggregate is tested for the specific gravity, water absorption, surface moisture and fineness modulus. The test is done as per the IS 2386(Part-6):1963 and results obtained are represented in the following table: -

Table-III Test results on fine aggregate

Specific Gravity	2.63
Surface moisture	0.3%
Water absorption	1.146%
Fineness Modulus	2.55
Bulk Density	1.587

Coarse aggregate

For the sample coarse aggregate specific gravity, bulk density and water absorption test is performed. The result for this test is tabulated as follows; -

Table-IV Test results on coarse aggregate

Specific Gravity	2.65
Bulk Density	44.8%
Water absorption	0.38%

Alkaline activator

Alkaline activator creates a high pH environment and accelerates the reactions. Mainly two chemicals are used as the alkali activator in their estimated ratio. NaOH (Sodium hydroxide) and sodium silicate (Na_2SiO_3) are the alkali activator used in this experiment. These alkali liquids are prepare 24hr before the casting of concrete.

Sodium Hydroxide (NaOH)

Sodium hydroxide (NaOH) available forms of pellets, flakes and in powder forms. In the study, Commercial grade Sodium Hydroxide (NaOH) is used in the flakes form (97%-100% purity). These flakes are used to make the solution of required molarity.

Sodium silicate

Sodium silicates are available in the solution form (98% pure). These solutions are used in the various ratios with sodium hydroxide to prepare required degree of alkali activator solution.

B. MIX DESIGN

The mix design in the case of geo-polymer concrete is base on convention concrete but some variations. In the case of convention concrete, has design code method whereas GPC (Geopolymer Concrete) has no design method or codal provisions. With various molarities (8M, 10M, 12M) and ratio (1:2.5, 1:2 and 1:1.5) are used. Mix design for 1 m^3 as per the previous research and the conventional data are as follows

Table V. Mix design for varying ratio

AAR	GGBS (Kg/m^3)	F.A (Kg/m^3)	C.A (Kg/m^3)	NaOH (Kg/m^3)	Na_2SiO_3 Kg/m^3
1:1.5	414	660	1136	53	79.5
1:2	414	660	1136	53	106
1:2.5	414	660	1136	53	133

C. PREPARATION OF SPECIMEN

The specimen is prepared for the compressive, flexural and split tensile test using the mix design.

Fig. 1: Concrete mixing machine

Fig. 2.1: concrete vibrator

Fig. 2.2: concrete mould

Fig. 2.3: geopolymer concrete cubes

III. OBSERVATION AND TEST RESULT

In this experimental study, compressive strength, flexural strength and split tensile strength for various molarity with varying alkali activator ratio is done.

The major parameter considered are; -

a) Molarity of sodium hydroxide

b) Ratio of sodium hydroxide (NaOH) to sodium silicate (Na_2SiO_3) by mass

c) Curing period

The test results are tabulated as;-

Table VI Compressive strength for varying molarity with varying ratio at 7 and 28 days

Molarity	7 days (MPa)			28 days (MPa)		
	1:1.5	1:2	1:2.5	1:1.5	1:2	1:2.5
8M	41.3	43.6	45.3	47.3	50.3	48.0
10M	44.1	46.6	53.8	51.0	54.9	60.3
12M	47.6	50.1	55.0	56.0	59.8	68.7

Table -VII Flexural strength for varying molarity with varying ratio at 7 and 28 days

Molarity	7 days (MPa)			28 days (MPa)		
	1:1.5	1:2	1:2.5	1:1.5	1:2	1:2.5
8M	3.97	4.03	4.06	5.84	6.02	5.89
10M	4.50	4.60	4.96	6.43	6.67	6.99
12M	5.11	5.28	5.74	7.10	7.34	7.87

TABLE -VIII Split tensile strength for varying molarity with varying ratio at 7 and 28 days

Molarity	7 days (MPa)			28 days (MPa)		
	1:1.5	1:2	1:2.5	1:1.5	1:2	1:2.5
8M	2.93	2.97	3 .08	4.49	4.63	4.53
10M	3.46	3.53	3.81	4.67	4.85	5.08
12M	4.15	4.29	4.67	4.97	5.138	5.50

The graph obtained from these experimental results are; -

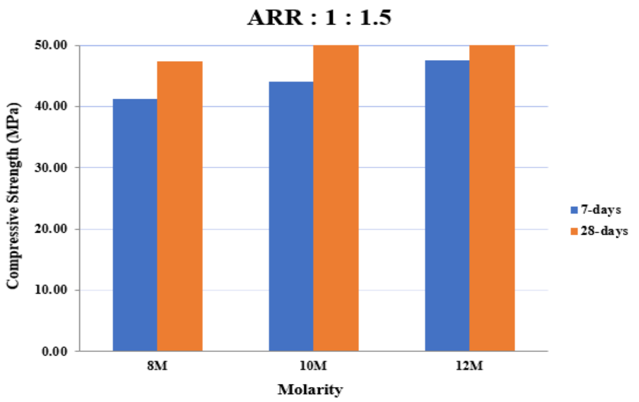

Fig. 3.1: Compressive strength for varying molarity for AAR 1:1.5

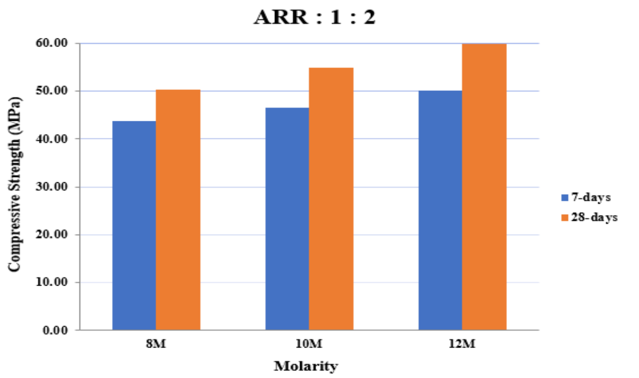

Fig. 3.2: Compressive strength for varying molarity for AAR 1:2

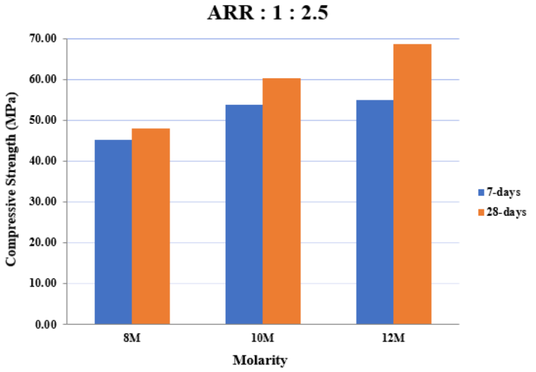

Fig 3.3: Compressive strength for varying molarity for AAR 1:2.5

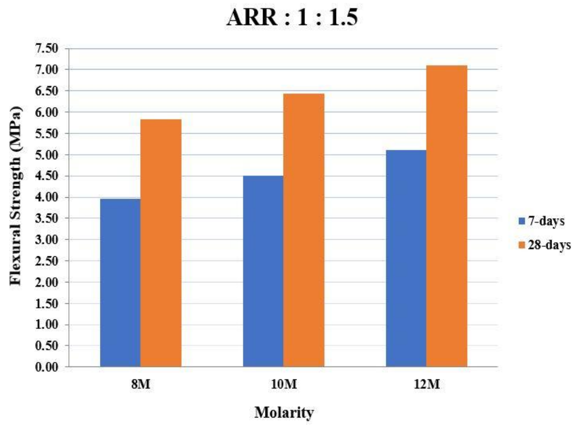

Fig 3.4: Flexural strength for varying molarity for AAR 1:1.5

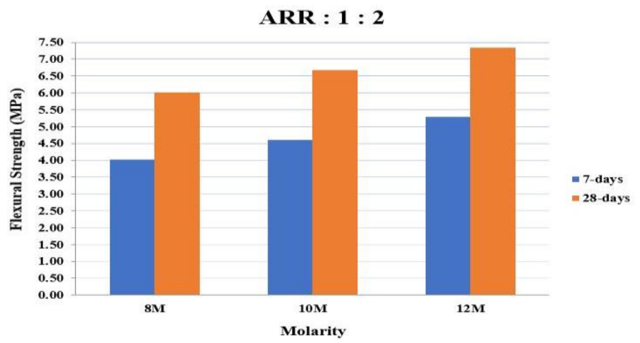

Fig. 3.5: Flexural strength for varying molarity for AAR 1:2

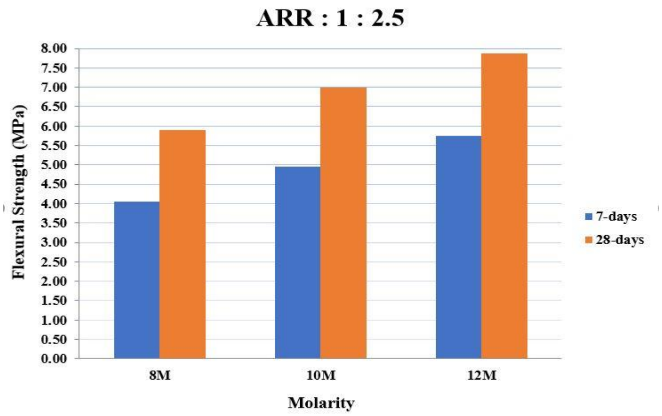

Fig 3.6: Flexural strength for varying molarity for AAR 1:2.5

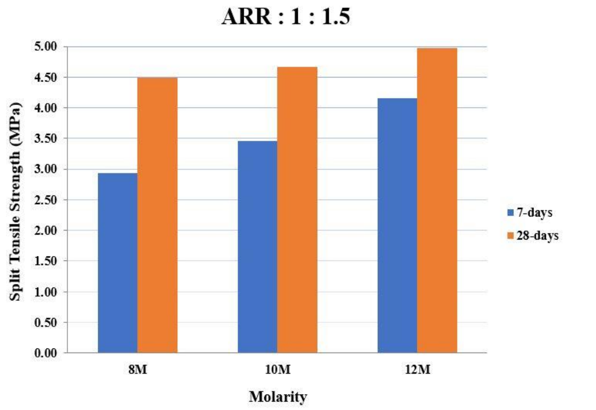

Fig 3.7: Split Tensile strength for varying molarity for AAR 1:1.5

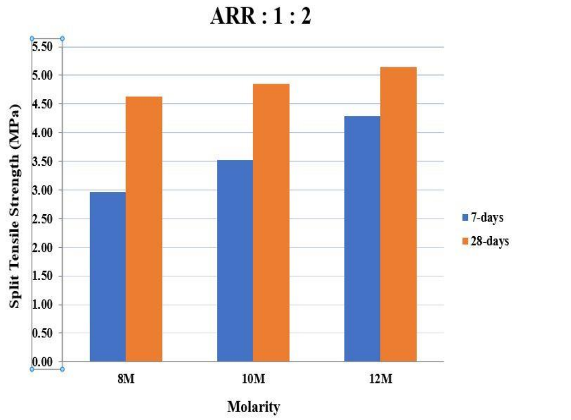

Fig 3.8: Split Tensile strength for varying molarity for AAR 1:2

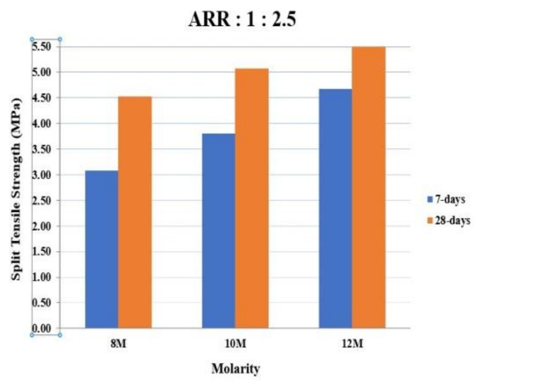

Fig 3.9: Split Tensile strength for varying molarity for AAR 1:2.5

1. From figure 3.1, 3.2 and 3.3, it can be observed that for a fixed AAR the Compressive Strength increases with increase in Molarity.
2. Also, for the fixed value of Molarity, the Compressive Strength increases with the increase in AAR.
3. From figure 3.4, 3.5 and 3.6, it can be observed that for a fixed AAR the Flexural Strength increases with increase in Molarity.
4. Also, for the fixed value of Molarity, the Flexural Strength increases with the increase in AAR.
5. From figure 3.7, 3.8 and 3.9, it can be observed that for a fixed AAR the Split Tensile Strength increases with increase in Molarity.
6. Also, for the fixed value of Molarity, the Split Tensile Strength increases with the increase in AAR.

IV. CONCLUSION

The obtained data from the experimental work carried out clearly indicates the increment in Compressive, Flexural and Split Tensile Strength of GGBS based Geopolymer Concrete with the increment in Molarity of NaOH. Also, the Mechanical Properties increased with the increment of AAR. The research suggests GPC prepared from higher Molarity and AAR are preferable in case of construction work demanding higher values of strength properties.

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