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Fresh and Mechanical Characteristics of Alkali Activated Fly Ash Slag Concrete Activated with Neutral Grade Liquid Glass

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Abstract: The development and use of geopolymer concrete continues to evolve as researchers and engineers refine mix designs, develop standardized guidelines, and explore new applications. One of the key benefits of geopolymer concrete is its lower carbon footprint compared to traditional Portland cement concrete. This reduction in carbon emissions is due to the elimination of clinker production, which is energy intensive and emits significant amounts of carbon dioxide. This sustainable alternative to Portland cement concrete plays an important role in reducing the environmental impact of the construction industry. Many prior studies on fly ash-slag based geopolymers have primarily focused on the characteristics of concrete that has undergone heat curing. This approach is seen as a constraint when it comes to in-situ casting applications in ambient conditions. Ambient curing of geopolymer concrete is a more energy-efficient and environmentally friendly option compared to heat curing, as it doesn't require the use of specialized curing chambers or high temperatures. However, it may require longer curing times to achieve the desired strength and making it important to plan the construction schedule accordingly. An experimental study was carried out using neutral grade liquid glass with a silica modulus (SiO2/Na2O) of 2.92 coupled with combinations of fly ash and Ground Granulated Blast Furnace Slag (GGBS) in proportions of 30:70, 50:50. The primary aim is to explore how altering the ratios of fly ash and GGBS impacts the mechanical characteristics of the resultant concrete for different solution/ binder ratios (0.6, 0.65 and 0.7) with a fixed binder quantity of 400 and 500 Kg/m3 under ambient curing conditions. The experimental program employed the fractional factorial method of experimentation to minimize the number of mix variations. In general, the findings indicated that higher levels of neutral-grade sodium silicate led to improvements in all mechanical properties. Conversely, an increase in the alkaline solution-to- binder ratio and curing temperature had a detrimental impact on the alkali-activated slag concrete. Optimal results for hardening of concrete for demolding were obtained after two days of casting. The implications of this research could lead to the development of more sustainable and environmentally friendly alternatives in the field of construction materials.
Keywords: Fly ash, GGBS, Alkali activated concrete, Neutral Grade liquid glass, ambient curing, workability, compressive strength, split tensile strength, flexural strength.

I. INTRODUCTION

In constructions the most commonly used building material is concrete, its usage by the communities across the globe is second only to water. It is well known that concrete is a mixture of Ordinary Portland Cement(OPC), sand, coarse aggregate and water and cement acts as a binding material when water is added. The usage of OPC is increased to meet infrastructure developments. In the future the demand for OPC would increase further around the world. However, the utilization of cement causes pollution to the environment and reduction of raw material. Cement is one of the most energy intensive materials, after steel and aluminum. The manufacturing of OPC requires the burning of large quantities of fuel and decomposition of limestone, resulting in significant emissions of carbon dioxide (Kong and Sanjayan). During the production about 1.5 tons of raw materials is needed in the production of every ton of Portland cement, at the same time about one ton of Carbon Dioxide (CO_2) is released in to the environment, thus contributing to 7% of world CO_2 emissions (McCaffery R).

On the other hand, coal burning power generation plants produce huge quantities of fly ash. The volume of fly ash would increase as the demand for power increases. Most of the fly ash is considered as waste and dumped in landfills. In order to address the issues mentioned above, it is essential that other forms of binders must be developed to make concrete.

It is necessary to reduce the use of cement may be by partially replacing the use of cement in concrete like high volume fly ash concrete and by developing alternate material like geopolymer concrete. In case of High-volume fly ash concrete more than 50% of cement can be replaced. But Geopolymer concrete is concrete which does not utilize any Portland cement in its production.

II. GEOPOLYMER CONCRETE

In 2001, the authors embraced Davidovits original concept of geopolymers to make fly ash-based geopolymer concrete. Geopolymer is an inorganic alumino-silicate polymer synthesized from predominantly silicon (Si) and aluminum (Al) materials of geological origin or by-product materials such as fly ash. The term geopolymer was introduced by Davidovits.J to represent the mineral polymers resulting from geochemistry. The process involves a chemical reaction under highly alkaline conditions on Si-Al minerals, yielding polymeric Si-O-Al-O bonds in amorphous form. It has been reported that geopolymer material does not suffer from alkali-aggregate reaction even in the presence of high alkalinity (Davidovits J), and possesses excellent fire-resistant Cheng, T W & JP Chiu.

The silicon and the aluminum in the fly ash are activated by a sodium silicate solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials. The role of binder in geopolymer concrete is replaced by fly ash which also possesses pozzolanic properties as OPC and rich with alumina and silicate. Fly ash is residue from the combustion of coal which is widely available worldwide and lead to waste management proposal. Hence, fly ash- based geopolymer concrete is a good alternative to overcome the abundant of fly ash. In fly ash-based geopolymer concrete, the silica and the alumina present in the source materials are first induced by alkaline activators to form a gel known as aluminosilicate.

This gel binds the loose aggregates and other unreacted materials in the mixture to form the geopolymer concrete (Wallah, SE). Besides that, the reaction also depends on a few parameters such as size of aggregates, chemical composition of fly ash, amount of vitreous phase in fly ash, nature, concentration and pH of activators. The curing process of geopolymer concrete play shows a great influence on the development of microstructure, and subsequently on the mechanical characteristics of geopolymer (Komljenovic et al.,). The strength of geopolymer depends on the nature of source materials. Geopolymers made from calcined source materials, such as metakaolin (calcined kaolin), fly ash, slag etc., yield higher compressive strength when compared to those synthesised from non-calcined materials, such as kaolin clay. The source material used for geopolymerisation can be a single material or a combination of several types of materials.

III. MATERIALS USED

The physical properties of fine aggregates, coarse aggregates, fly ash, GGBS and neutral grade liquid glass used for mix design Geopolymer concrete were tested in laboratory and are mentioned below.

A. Fine Aggregate

The fine aggregate conforming to IS 383-1970 in zone-II is used in mix. The sand which was locally available and passing through 4.75mm IS sieve size was used as fine aggregate. The physical properties of the fine aggregates are as listed in table below:

B. Coarse Aggregates

The coarse aggregates with nominal maximum size of aggregates as 20mm (60%) and 10mm (40%) as per Indian standard were used. The physical properties of the coarse aggregates are as listed in Table 1.

Table 1 Physical Properties of Coarse Aggregates and fine aggregates

S. No.	Properties	Coarse aggregates	Fine aggregate
1.	Specific Gravity	2.84	2.65
2.	Water absorption	0.5%	1.1%
3.	Fineness modulus	7.28	2.62

C. Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS), also known as slag cement or simply slag, is a byproduct of the iron and steel industry. The GGBS was procured from the JSW cement industry, Chennai.

D. Fly ash

Fly Ash is the finely divided mineral residue resulting from the combustion of powdered coal in Thermal power plants. The fly ash (class F) has been taken from the NTPC Simhadri Thermal power plant situated at near Vishakhapatnam**.**

Table 2 Physical and Chemical Properties of Fly ash and GGBS

S. No.	Properties	Fly ash	GGBS
1.	Specific gravity	2.05	2.85
2.	Magnesia (MgO), %	1.96	7.73
3.	SiO_2 Content, %	60.87	34.4
4.	CaO Content, %	1.110	40.5
5.	Fe_2O_3, %	6.08	2.62
6.	Al_2O_3, %	26.47	11.5

E. Neutral Grade Liquid Glass

Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In present investigation sodium silicate 2.92 (ratio between Na_2O to SiO_2) is used. As per the manufacture, silicates were supplied to the detergent company and textile industry as bonding agent. Same sodium silicate is used for the making of geopolymer concrete. The source of the alkaline liquid was obtained from Kiran global solutions TAMILNADU.

Table 3 Physical and Chemical Composition of Neutral Grade Liquid Glass(Na_2SiO_3)

Physical Properties			Chemical Properties		
1.	Colour&Appearance	Colorless	1.	Na_2O % by mass	9.55
2.	Specific Gravity	1.410	2.	SiO_2 % by mass	29.80
3.	Baume	42^o	3.	Weight Ratio	1 :3 :12
4.	Viscosity	-	4.	Molar Ratio	1 :3 :22
5.	Twaddle	-	5.	Total Solids	39.35
6.	Ph	12.2	6.	Chloride (Cl)	-

IV. METHODOLOGY

The aim of this paper is to study was carried out using neutral grade liquid glass with a silica modulus (SiO_2/Na_2O) of 2.92 coupled with combinations of fly ash and Ground Granulated Blast Furnace Slag (GGBS) in proportions of 30:70, 50:50. The primary aim is to explore how altering the ratios of fly ash and GGBS impacts the mechanical characteristics of the resultant concrete for different solution/ binder ratios (0.6, 0.65 and 0.7) with a fixed binder quantity of 400 and 500 Kg/m^3 under ambient curing conditions. To carry out the experimental investigation total 72 cubes of size 150mm x 150mm were casted. The compressive strength of specimens is determined after 7days, 28 days of curing respectively with surface dried condition as per Indian Standards. Moulds size 150 x 150 x 150mm was used for evaluation of compressive strength. This ultimate load divided by the cross-sectional area of the cube (150mm x 150mm) yields the compressive strength of concrete. Splitting tensile strength is an indirect method to determine tensile strength of concrete.

Splitting tensile strength of concrete was evaluated at age of 7 days, 28 days using standard cylindrical specimens of 150mm diameter and 300mm height. Compression Testing Machine (CTM) of 5000 KN capacity was used for the testing of compressive strength of concrete.

When concrete is subjected to bending stress, Compressive as well as tensile stresses are developed at top and bottom fibers respectively. The strength shown by the concrete against bending is known as flexural strength. The standard size of specimen is 150mm x150mm x700mm. The flexural beam specimens are tested at 7 days, 28 days. The average of three specimens was reported as the flexural tensile strength. Different mixes with varying combinations of GGBS and fly ash are considered for testing. Various tests are done on concrete at both fresh and hardened stage to evolve the Performance of the concrete.

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The combinations used are described below.

Mix – G1: GPC with 50:50 ratio, s/b ratio 0.6 and binder content 400 Kg/m^3
Mix – G2: GPC with 50:50 ratio, s/b ratio 0.65 and binder content 400 Kg/m^3
Mix – G3: GPC with 50:50 ratio, s/b ratio 0.7 and binder content 400 Kg/m^3
Mix – G4: GPC with 50:50 ratio, s/b ratio 0.6 and binder content 500 Kg/m^3
Mix – G5: GPC with 50:50 ratio, s/b ratio 0.65 and binder content 500 Kg/m^3
Mix – G6: GPC with 50:50 ratio, s/b ratio 0.7 and binder content 500 Kg/m^3
Mix – G7: GPC with 70:30 ratio, s/b ratio 0.6 and binder content 400 Kg/m^3
Mix – G8: GPC with 70:30 ratio, s/b ratio 0.65 and binder content 400 Kg/m^3
Mix – G9: GPC with 70:30 ratio, s/b ratio 0.7 and binder content 400 Kg/m^3
Mix – G10: GPC with 70:30 ratio, s/b ratio 0.6 and binder content 500 Kg/m^3
Mix – G11: GPC with 70:30 ratio, s/b ratio 0.65 and binder content 500 Kg/m^3
Mix – G12: GPC with 70:30 ratio, s/b ratio 0.7 and binder content 500 Kg/m^3

Table 4 Quantities of materials used for various mixes for 1 m^3

Mix Nomenclature	GGBS : Fly ash kg/m^3	Binder content kg/m^3	Solution to binder ratio	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Solution kg/m^3	Mix proportions
G1	(50:50)	400	0.6	837	1023	240	1 : 2.09 : 2.55 : 0.6
G2	(50:50)	400	0.65	828	1012	260	1 : 2.07 : 2.53 : 0.65
G3	(50:50)	400	0.7	819	1001	280	1 : 2.04 : 2.5 : 0.7
G4	(50:50)	400	0.6	765	935	300	1 : 1.53 : 1.87 : 0.6
G5	(50:50)	400	0.65	753.75	921.2	325	1 : 1.5 : 1.84 : 0.65
G6	(50:50)	400	0.7	742.5	907.5	350	1 : 1.48 : 1.81 : 0.7
G7	(70:30)	500	0.6	837	1023	240	1 : 2.09 : 2.55 : 0.6
G8	(70:30)	500	0.65	828	1012	260	1 : 2.07 : 2.53 : 0.65
G9	(70:30)	500	0.7	819	1001	280	1 : 2.04 : 2.5 : 0.7
G10	(70:30)	500	0.6	765	935	300	1 : 1.53 : 1.87 : 0.6
G11	(70:30)	500	0.65	753.75	921.2	325	1 : 1.5 : 1.84 : 0.65
G12	(70:30)	500	0.7	742.5	907.5	350	1 : 1.48 : 1.81 : 0.7

V. RESULTS AND DISCUSSIONS

A. *Workability*

The slump and compaction factor values for the designed mixes are as shown below even though the slump values of the mixes are very low, it was observed that when placed in the moulds and compacted has resulted in a very consistent and workable mix. The compaction factor values also suggest the mixes are stiff but, when subjected to vibration laitance formation and finishing are observed to be good. The values are as shown in the table 5. The specimens were cast with the same water content that is no correction is applied to the water content in order to improve the slump also, it was observed that the initial setting of the concrete didn't occur for 3 to 4 hours. The specimens were cured further at undisturbed room temperature by exposing to sun until the day of testing.

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Fig. 1 Slump Cone Test

Table 5 Slump values for different % of GGBS and Fly ash

S.no	Mix Id	slump value(mm)
1.	G1	100
2.	G2	120
3.	G3	145
4.	G4	95
5.	G5	115
6.	G6	130
7.	G7	100
8.	G8	110
9.	G9	125
10.	G10	95
11.	G11	105
12 .	G12	115

The average value of slump obtained for various mix combinations is plotted in Figure 2.

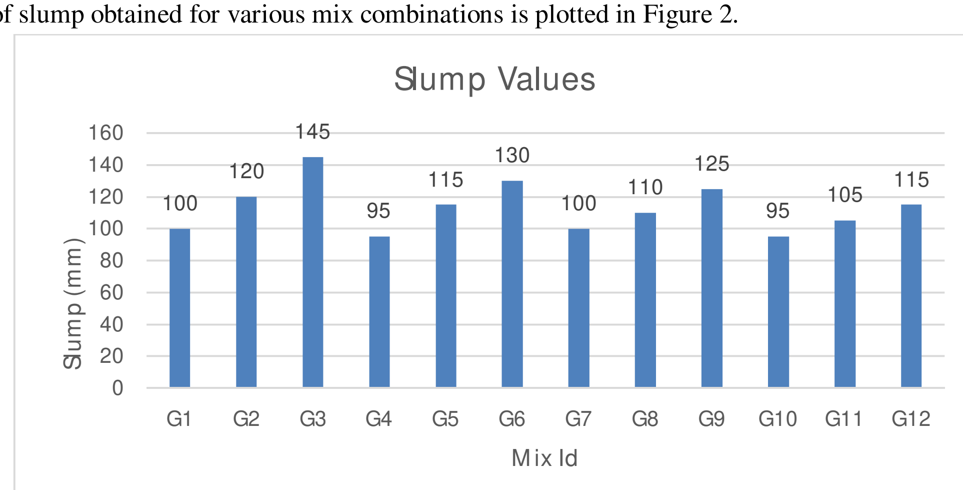

Fig. 2 Slump Values (mm)

Specimens of M25 grade are cast as per the procedure laid down in IS 456:2000 for the specified mix combinations. After 24 hours, the test specimens are demoulded and placed in fresh water tank for curing. After 7 days and 28 days they are tested for Compressive strength, Split tensile strength, Flexural strength. Based on 28 days strength Optimized % replacement of respective materials is determined.

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B. Compressive Strength Test

Higher amounts of binder in concrete consistently resulted in increased compressive strength. The strength exhibited a dependency on the binder quantity, especially in scenarios where the binder content was high. In such cases, the strength and binder content demonstrated independence from each other. The impact of prolonged curing on this property was more pronounced in AAFSC, indicating a heightened chemical reaction in progress during the curing process, leading to strength generation. The binder content and the liquid/binder ratio in AAFSC emerged as pivotal factors influencing the hardening rate and the ultimate strength of AAFSC. It is noteworthy that elevating the solution content had a positive effect up to a certain threshold limit, after it is increasing the compressive strength of concrete.

Fig. 3 Compressive strength test

The compressive strength of the concrete was done on 150x150x150mm cubes, A total of 72 cubes were cast for the 12 mixes. i.e., for each mix 3 cubes were prepared. Testing of specimens was done at 7 days and 28 days at the rate of three cubes for each mix on that particular day. The average value of the 3 specimens is reported as the strength at that particular age.

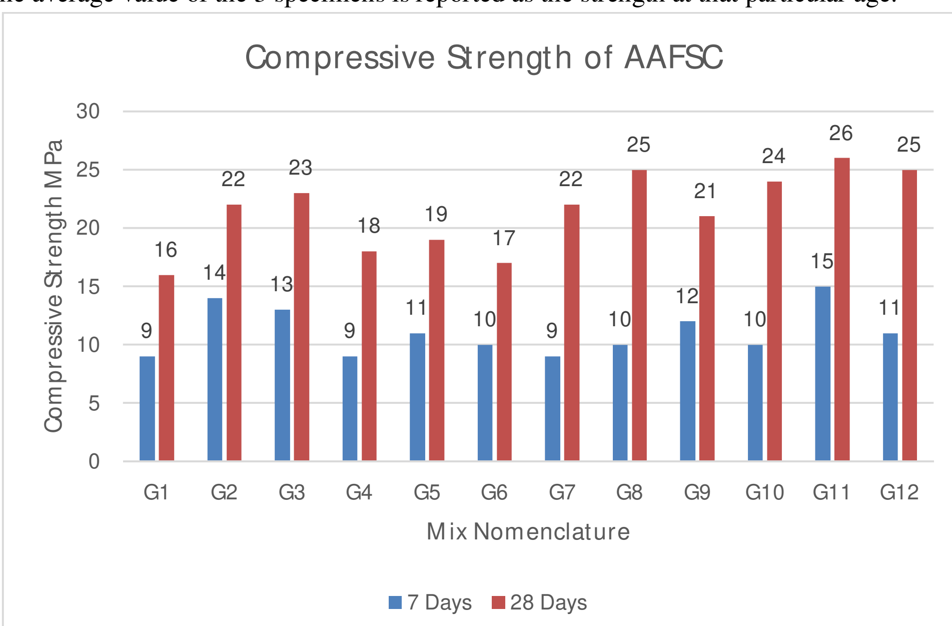

Fig. 4 Compressive Strength for various mixes at 7 and 28 days

1) Observations

From the results it can be observed that the with the increase of GGBS content in the binder, the compressive strength of 28 days values increase from 16-26 MPa with increasing 62.5%, G11 mix have achieved more compressive strength compared to the remaining mixes.

As there is no standard mix design procedure available for geopolymer concrete mix the results cannot be compared with the design mix values of OPC concrete. However, Comparision was carried out with nominal values of OPC concrete.

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C. Split Tensile Strength Test

Enhancing our comprehension of the engineering characteristics of AAFSC formulated with a neutral-grade sodium silicate is unquestionably crucial for the efficient implementation of this material. The enhancement in tensile strength exhibited a substantial increase as the binder quantity. As the compressive strength of AAFSC increased, a corresponding rise in split tensile strength was observed. These findings suggest that AAFSC mixes with binders demonstrate commendable mechanical properties when cured under ambient conditions without the need for additional heat. The tensile strength was measured on 150x300 mm cylinders and the results were shown below. A total of 24 cylinders were cast for the 12 mixes. These specimens were tested each time and the average values at the age was reported as the tensile strength of this concrete.

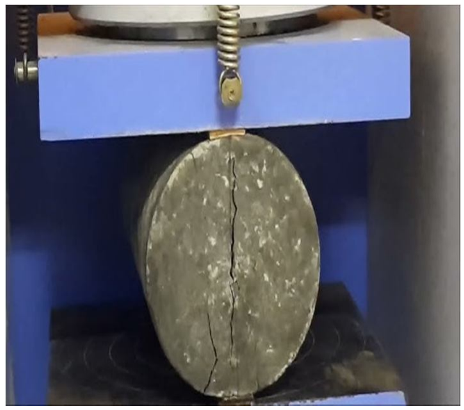

Fig. 5 Split tensile strength

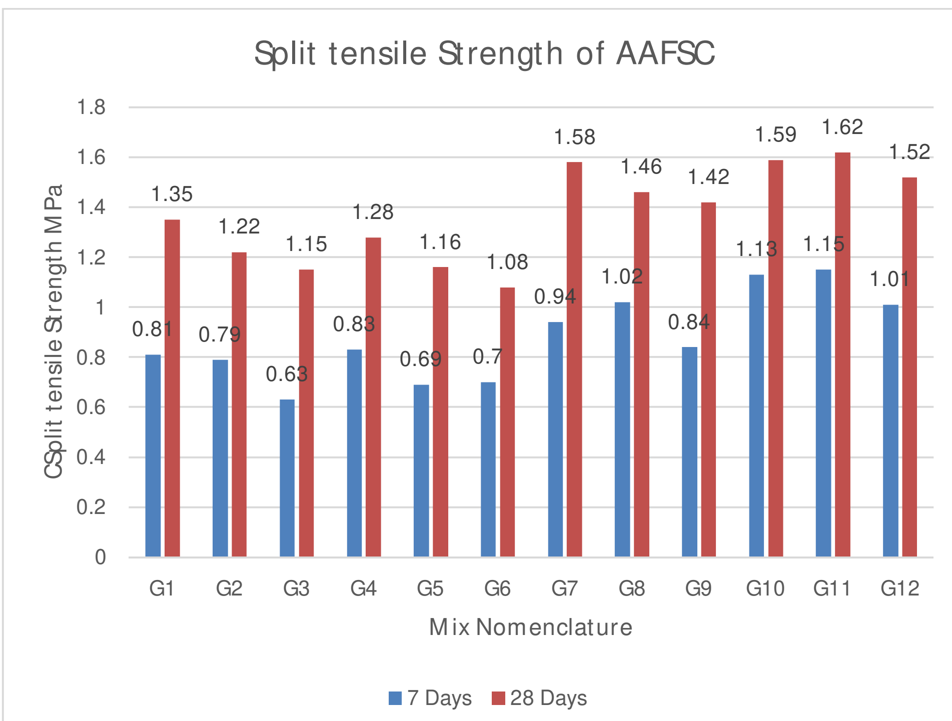

Fig. 6 Split Tensile Strength for various mixes at age 7 and 28 days

1) Observations

From the results it can be observed that the split tensile strength of 28 days values increases from 1.08-1.62 MPa with increasing 50%, G11 mix have achieved more split tensile strength compared to the remaining mixes.

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D. Flexural Strength Test

Understanding and optimizing the flexure strength of geopolymer concrete is essential for ensuring its effectiveness in structural applications and promoting its use as an environmentally friendly alternative to traditional concrete. Flexural strength of the concrete was determined from modulus of rupture test on beam specimens of 150mmx150mmx700mm size. Here also, a total of 24 specimens were cast out of which one specimens were tested for each mix at 7 days, 28 days.

Fig. 7 Flexure strength test

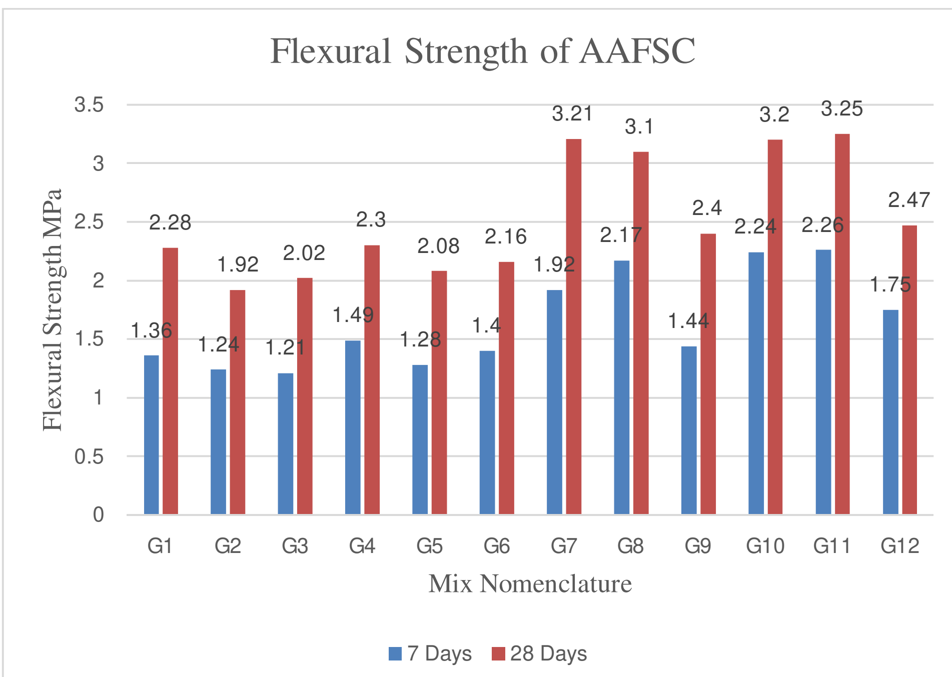

Fig. 8 Flexural Strength for various mixes at age 7 and 28 days

1) Observations

From the results it can be observed that the flexure strength of 28 days values increases from 1.92-3.25 MPa with increasing 67.1%, G11 mix have achieved more flexure strength compared to the remaining mixes. The compressive strength, split tensile strength and flexural strength values for all mix combinations are tabulated in Table 6.

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Table 6 Compressive strength, split tensile strength and flexural strength values of various mixes at 7 days and 28 days

MIX ID	% of GGBS	% of Fly ash	Compressive strength (MPa)		Split tensile strength (MPa)		Flexural strength (MPa)	
			7 days	28 days	7 days	28 days	7 days	28 days
G1	50	50	9	16	0.81	1.35	1.36	2.28
G2	50	50	14	22	0.79	1.22	1.24	1.92
G3	50	50	13	23	0.63	1.15	1.21	2.02
G4	50	50	9	18	0.83	1.28	1.49	2.3
G5	50	50	11	19	0.69	1.16	1.28	2.08
G6	50	50	10	17	0.70	1.08	1.40	2.16
G7	70	30	9	22	0.94	1.58	1.92	3.21
G8	70	30	10	25	1.02	1.46	2.17	3.1
G9	70	30	12	21	0.84	1.42	1.44	2.4
G10	70	30	10	24	1.13	1.59	2.24	3.2
G11	70	30	15	26	1.15	1.62	2.26	3.25
G12	70	30	11	25	1.01	1.52	1.75	2.47

VI. CONCLUSIONS

Based on the concept of geopolymer technology number of trial mixes were carried out to develop a process of manufacturing fly ash based geopolymer concrete and by using the technology currently used to manufacture Ordinary Portland Cement concrete. This experimental work carried out to study the fresh and hardened properties of geopolymer concrete. After several trials at the outset, the mix design developed for the geopolymer concrete with low calcium fly ash yielded good results.

By this experimental work, the following conclusions are drawn.

1) The slump values of the mixes were very low but, the mixes were consistent and workable. Also, the slump observed was true slump.
2) Geopolymer concrete gained strength rapidly than ordinary concrete Around 75 to 80% of the characteristic strength was gained in the first 3 days. Strength increased was nominal after 3 days.
3) The neutral grade liquid Na_2SiO_3 used as an activating solution in the preparation of the AAGC increased the IST and FST values by avoiding the rapid setting of the concrete. To improve the setting time, no retardants or water reducers were added while mixing the concrete.
4) The increase in the slag percentage in the binder reduced the setting time and slump values of the fresh concrete and enhanced the compressive, split tensile and flexural strengths of the hardened concrete at ambient room temperature curing at all the stages.
5) With all the binder contents, increasing the liquid/binder ratio above a certain level does not add to the strength but increases the workability, while the AAFSC mixes with a low liquid/ binder ratio are less workable.
6) The AAFSC has the maximum slump with the minimum compressive strength, but it is reversed in the AAGC. It is concluded that the AAFSC prepared with neutral grade Na_2SiO_3 can be designed for various slump values and AAFGC grades.
7) The development in the rate of the strength gain in the AAGC at the initial stage was more than in the later stage, whereas, the strength gain rate of the AAFC was very slow in the first 7 days, but it increased rapidly with the stages.
8) With the increase of GGBS content in the binder, the compressive strength of 28 days values increases from 16-26 MPa with increasing 62.5% , G11 mix have achieved more compressive strength compared to the remaining mixes.
9) The split tensile strength of 28 days values increase from 1.08-1.62 MPa with increasing 50%, G11 mix have achieved more split tensile strength compared to the remaining mixes.

10) The flexure strength of 28 days values increase from 1.92-3.25 MPa with increasing 67.1%, G11 mix have achieved more flexure strength compared to the remaining mixes.
11) In AAFSC, replacement of Fly ash with GGBS exhibits improved performance in terms of workability and compressive strength which results in the reduction of environmental effects.

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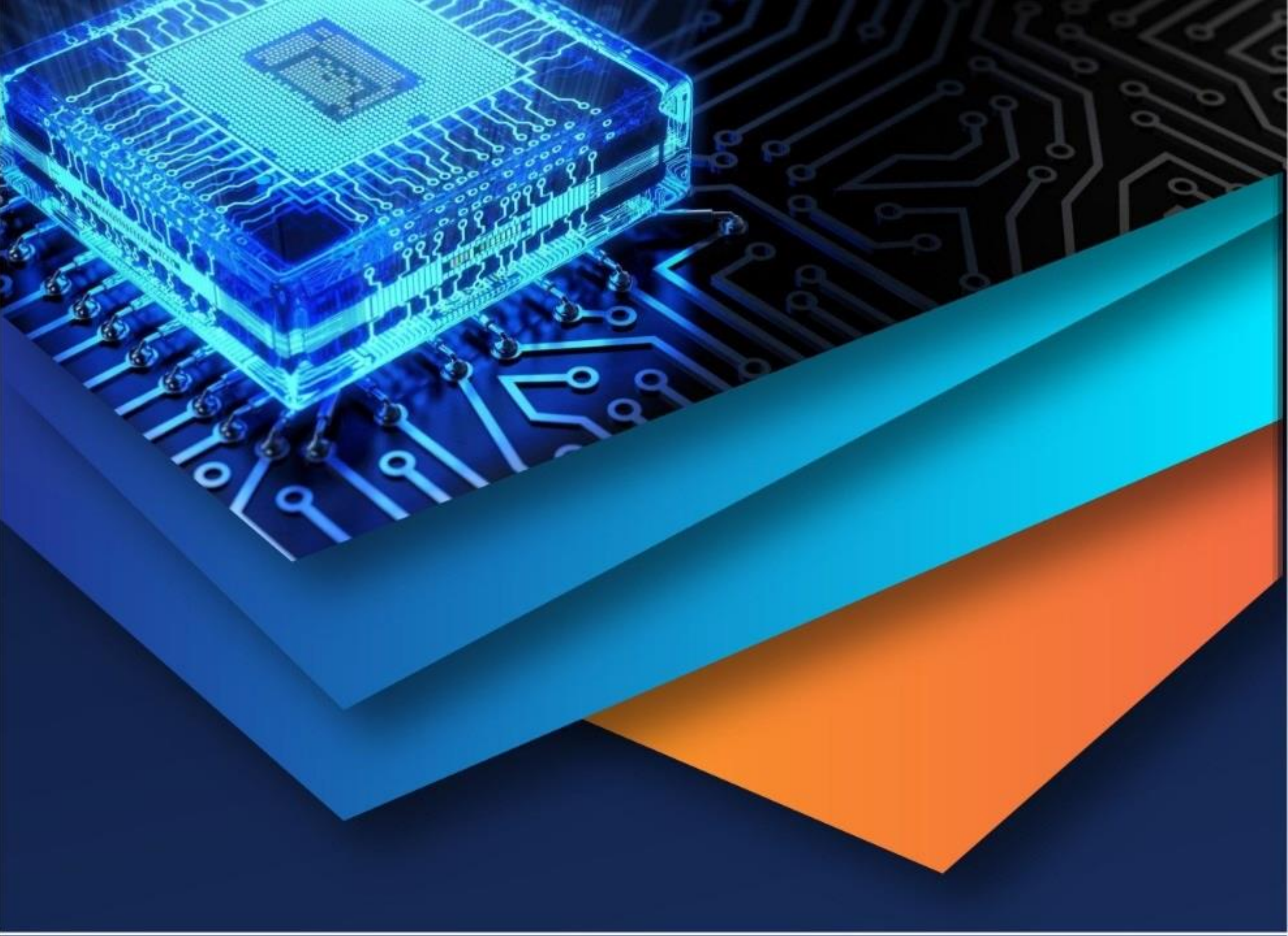

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