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An Experimental Study on the Mechanical Characteristics of Flyash and Slag Based Geopolymer Concrete Activated With Neutral Grade Sodium Silicate Solution

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ABSTRACT:
The rapid growth of construction development in the recent times and limited natural resource available to produce the concrete needed to focus on the alternative material. Instead of using the conventional concrete material, the industrial waste material utilization is more beneficial to reduce the carbon emission and sustainable for the conventional concrete sources. The alumina and silicate are main elements in the formation of the CSH gel, that related to the gain the strength of the concrete. The industrial waste of fly ash and ggbs are rich in the alumina and silicates. Through, many research activities have been carried on the alkali activated concrete but still there was some challenge remained in the geopolymer concrete.GGBS was employed in the formulation of Alkali-activate fly ash slag concrete(AFSC) through the utilization of a sodium silicate solution with a silica modulus (Ms) of 2.92. This was done to evaluate the efficacy of the solution in controlling the rapid setting characteristics of GGBS.

A study was conducted to assess the feasibility and strength of concrete across various solution/binder ratios (0.45, 0.50, and 0.55) as well as the fixed binder quantities of 450 kg/m³ with a fly ash to ggbs proportion of 40:60, 50:50, and 60:40 under the ambient temperature. The alkali activated slag concrete has been adversely impacted by the rise in alkaline solution/binder and curing temperature. This paper describes research carried on the mechanical properties of Alkali activated fly-ash slag concrete under the ambient curing condition with various alkali activated binder ratios.

Keywords: Alkali activated concrete, Neutral Grade liquid glass, ambient curing, Compressive Strength, Split tensile Strength, and Flexural Strength.

I. INTRODUCTION

After water, concrete is used the second most frequently worldwide. Ordinary Portland Cement (OPC) has been used as the main binder in the manufacturing of concrete for many years.Huge volumes of greenhouse gases are released into the atmosphere because of cement manufacture, which negatively impacts the environment by causing ozone layer thinning. About 90% of the total CO2 emissions from industrial operations worldwide come from the cement industry[1]. The massive volumes of CO2 that are emitted because of the de-carbonation of CaCO3 according to the following equation make cement manufacture a well-known example of an unfriendly industry to the environment: $CaCO_3 \rightarrow CaO + CO_2$[2]. Only the next 50 years' worth of OPC production will be possible with the current supply of limestone[3]. To overcome this, it is necessary to develop an alternative geopolymer cement OPC and green and sustainable concrete production.With the rising industrialization and urbanisation of the contemporary period, there is an annual growth in the demand for construction materials worldwide. More naturally occurring cementitious by-products are required to meet the rising demand for construction. Currently, components such as ground granulated blast furnace slag (GGBS), red mud, fly ash, silica fume, metakaolin, and graphene powder are used in addition to or as a partial substitution for OPC concrete to achieve improved physical and durable properties.Considering their mechanical characteristics and economics, a complete replacement of these materials is not appropriate. It is necessary to look for an OPC paste substitute that emits less CO2 and makes use of waste by-products.Academics and the concrete industry have given geopolymer concrete a lot of attention in this situation.Excellent plastic characteristics, as well as additional qualities including exceptional resistance to thermal stability chemical attack, or even smartness were widely reported in addition to environmental friendliness[3]. Since the last 20 years, the scientific community has been very interested in the study and development of alkaline-activated materials, particularly cement and concrete, due to the product's significant potential as environmentally friendly substitutes for Portland cement binders[4].

The alkali activation of fly ash binder with an activator prepared with sodium hydroxide and liquid Na_2SiO_3, which requires a high concentration of NaOH and heat curing, has been proposed to increase the initial age strength of alkali-activated fly ash concrete (AAFC)[5]. A GGBS binder may generate high strength AAGC without oven curing, however the main problem of GGBS is the concrete's quick setting behaviour, which leads to low workability. AAFGC has demonstrated appealing technical characteristics, and by optimizing the fly ash/GGBS proportions, its engineering performance can be improved[6].The silica modulus, or SiO_2/Na_2O ratio, is the most significant property of Na_2SiO_3. Ms values for liquid Na_2SiO_3that is readily accessible in commerce range from 1.6 to 3.85.A water glass is impractical and less stable. Increases in the SiO_2 to Na_2O ratio result in an increase in the rate of geopolymer polymerization. The process of hydrating alkali-activated slag is influenced by the sodium concentration and the SiO_2 to Na_2O ratio of water glass. For AAGC mixtures, it was reported that using water glass with M_s between 1 - 2 produces the best results.Instead of using a mixture of $Na_2SiO_3$and NaOH, it is beneficial to utilize a liquid Na_2SiO_3 single solution.By adding the amount of GGBS, which fly ash-based GPC may be utilized without being heated, giving it characteristics comparable to those of OPC. Workability and setting time are decreased when GGBS is added to Fly Ash. Although compressive strength decreased as alkaline activator setting time increased[7].

Geopolymer concrete activated with Na_2SiO_3 and NaOH are discussed in past literatures, but geopolymer concrete activated with single alkaline solution Na_2SiO_3 is focused. In the current investigation, neutral grade water glass with a silica modulus of 2.9 is used to activate alkali activated concrete to assess setting time, workability, and compressive strength without adding the water.

II. MATERIALS

2.1Binders

The binder ingredients that were used in thisinvestigation are Class-F fly ash and ggbs.The Simhadri thermal power plant (NTPC) has provided the fly ash that was utilized in the current study,located in Visakhapatnam, Andhra Pradesh, India, having specific gravity 2.23 and surface fineness 390 m^2/kg.

The GGBFS used in this investigation was purchased from ASTRA Chemical Ltd, located in Chennai, India, having specific gravity 2.91 and surface fineness 410 m^2/kg.

Table1 ChemicalcompositionofFlyAshandGGBS

Chemical Composition	**FlyAsh (%)**	**GGBS (%)**
SiO_2	56.4	33.57
Al_2O_3	28.32	17.4
Fe_2O_3	9.61	0.72
CaO	2.82	39.6
MgO	0.75	6.68
Na_2O	0.27	0.31
SO_3	0.36	1.23
Lossofignition	0.74	Nill

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2.2 Aggregates

The fine aggregate used in the present was locally available fresh Godavari River basin sandwith a specific gravity of 2.65. According to IS 383:1970, the fine sand material is cleaned from dust, dried from moisture content, and stored in a fresh location before use. The sieve analysis test was conducted on the fine aggregate, and it was determined to be in zone II.The properties of the fine aggregate, such as particle size distribution, shape, and surface texture, can influence the performance of the geopolymer concrete in terms of workability, strength, and durability.

The coarse aggregate was taken from the locally available crushed aggregate industry with a specific gravity of 2.71. Distinctive sizes of coarse aggregates such as 4.75, 10, and 20 mm are utilized in equal proportion for this experimental work. The fine and coarse aggregates had fineness modulus values of 2.65 and 6.28 respectively.

2.3 Activator

The silica modulus (M_S) SiO_2:Na_2O ratio rangesbetween 2:1 and 3.75:1.$M_S$value>2.85 are treatedas neutral grade and $M_S$value <2.85 are treated asalkaline. In this study, a single alkaline activator was used with a specific gravity of 1.45 and silica modulus (M_S) 2.92:1 with 28.98% SiO_2, 9.92%Na_2O by weight and pH 12.9, which isobtainedfromKiranGlobalLimited,Chennai,India.

III. EXPERIMENTAL PROGRAM

3.1Procedure for mixing and Casting of Concrete

This study primary focusedon fundamental characteristicsofalkali activated concrete such as consistency and setting time. Secondly, slump and compressive strength tests were carried out to determine the workability and strength of the alkali activated concrete. Using the Vicat's apparatus, consistency, initial setting time (IST), and final setting time (FST) tests for the paste were carried out in accordance with IS: 4031 (parts 4)[8]and IS: 4031 (part 5) 1988[9] respectively.The Vicat plunger, which has a diameter of 10 mm, can penetrate the paste to a point 5-7 mm from the bottom of the Vicat mould at a normal consistency. A steel needle that acts at a specified weight of 300 ± 1 g penetrates the paste in the device. Every 10 minutes, the sample was re-penetrated and kept at a controlled temperature of (20 ± 2)°Cwith a relative humidity of 90%. To calculate IST and FST, two different needles were used. A right cylinder with a diameter of 1.13 ± 0.05 mm served as the initial set's needle. The IST was recorded so that the needle does not penetrate more than 4±1mmfrom the bottom when the sample is sufficiently stiff.

Initial dry mixing took place for two to three minutes with the binder, fine aggregates, and coarse aggregates. The dry mixture was then combined with the activator, and the mixture was stirred for 5 to 7 minutes to achieve uniformity.To determine the workability of all concrete mixtures, a slump test based on IS 1199-1959 was conducted using a metallic slump mould. It was measured and reported as slump, which is the level difference between the height of the mould and the highest point of the subsided concrete.After measuring theworkability, the steel moulds of dimensionsof 100 mm x 100 mm x 100 mm were used to cast the nine batches of concrete mixes, then compacted and vibrated in mould with a period of 10-30 seconds depending on workability of concrete. The specimenswere demoulded after 24 hours of casting time and placed at room temperature till the testing day of the concrete specimen.Compressive strength tests were conducted for the adopted mixes according to IS: 516-1959.

3.2 Mix design

In this current study, the experimental program was conducted on the fresh and mechanical behaviour of alkali activated concrete activated with neutral grade liquid glass of silica modulus (M_s) 2.92 for different activator/ binder ratio of 0.45, 0.5 and 0.55 and with a fixed binder content of 450 kg/m^3.

TABLE3.1Weight contentsinthemixes

Bindercontent (Kg/m^3)	450	450	450
Activator/Binder	0.45	0.50	0.55
Fine aggregate(Kg/m^3)	787	776	766
Coarse aggregate(Kg/m^3)	961	949	936
Activator(Kg/m^3)	202	225	248

The percentage of fly ash and ggbs used in various combination of 40:60, 50:50, and 60:40 respectively. The compressivestrengths characteristics were evaluated for the age of 7, 14, and 28 days. Since, there is no specific mix design for geopolymer concrete, so the design methodology used was nearly identical to that of conventional PC concrete. The adopted mix proportions were tabulated below in table 3.2.

TABLE3.2Mixproportions

Names for Mixes	Fly Ash (%)	GGBS (%)	A/B Ratio	B: FA: CA: A/B
G1	40	60	0.45	1:1.74:2.13:0.45
G2	50	50		
G3	60	40		
G4	40	60	0.50	1:1.70:2.09:0.5
G5	50	50		
G6	60	40		
G7	40	60	0.55	1:1.67:2.04:0.55
G8	50	50		
G9	60	40		

Where:B-Binder content(kg/m^3), A- Activator Solution (kg/m^3), A/B-Activator/Binder ratio, FA-Fineaggregate(kg/m^3), and CA-Coarseaggregate(kg/m^3)

IV. RESULTS AND DISCUSSION

Nine mixtures of geopolymer have been prepared to investigate the effect of different parameters on workability and compressive strength in concrete samples cured at ambient temperatures. The results shall be compared with variations in one of the parameters at a time and each parameter shall continue to remain unchanged.

4.1 Standard consistency and setting time.

Alkaline solution was the sole liquid component used in the mix design of geopolymer concrete. Superplasticizer and water were not supplemented in any way of the concrete, instead of moisture content in the aggregate, which was also used in saturated surface dry condition.In the absence of a significant amount of additional water or superplasticizer, the activator produces a thick and cohesive paste with fly ash. As a result, the geopolymer paste and aggregate mixture exhibit good cohesion. When the liquid quantity is relatively low, the mixture might become quite stiff. However, these characteristics vary with the variation of the activator content.

TABLE4.1 Fresh properties of alkali activated flyash/ggbs paste.

Flyash/Ggbs (%)	Normal Consistency (%)	Initial setting time (minutes)	Final setting time (minutes)
100:0	34	1120	1740
60:40	37	460	980
50:50	39	380	740
40:60	40	320	680
0:100	45	110	240

4.2 Workability

In general, a geopolymer combination has a different rheology than an OPC mixture. Because of this, the findings of traditional slump and flow tests on geopolymers do not reflect the same degree of workability as in OPC mixes.The workability of concrete as evaluated by slump often showed a greater consistency of themixture with a higher liquid content. The slump values of all nine mixes were graphically represented in fig:1. It is observed that the slump value increases with the increase in activator to binder ratio. It is also evident from the fig:1 that 60:40 proportion of fly ash to ggbs has shown better workability for each A/B ratio.

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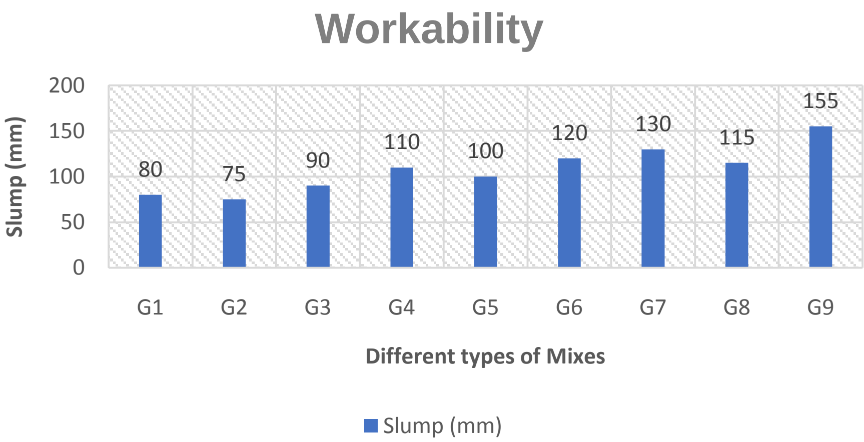

Fig1:workabilitywithdifferentmix proportions

4.2 Compressive Strength

The compressive strength characteristics for all the nine mix proportions of the age of 7, 14, and 28 days are represented in the fig 2. The compressive strength of the alkali activated concrete is observed to be decreasing with the increment of fly ash and decrement of ggbs proportions for all A/B ratios. It is seen that the highest compressive strength was obtained at a activator to binder ratio of 0.55 for 40:60 proportion of fly ash and ggbs.

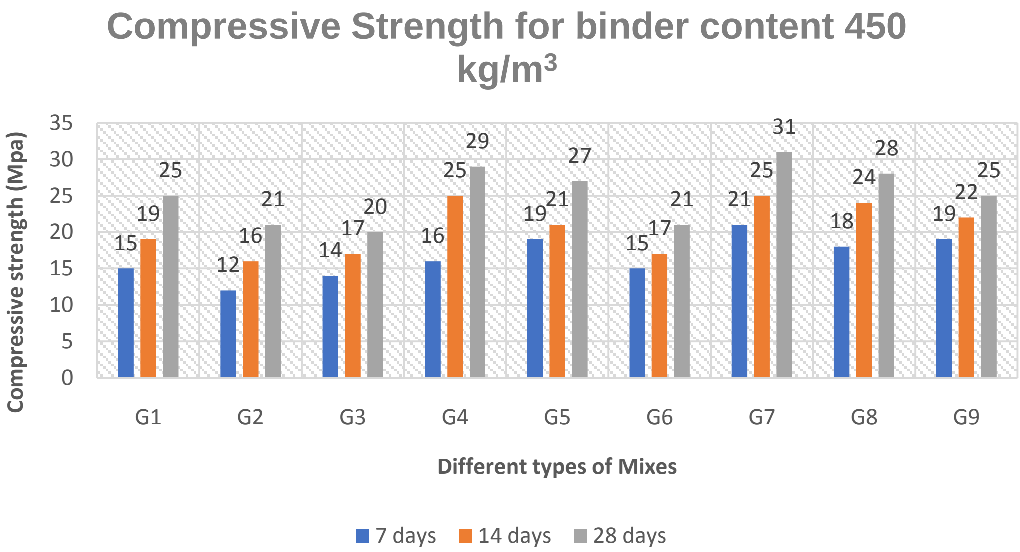

Fig2:Compressive Strengthwithdifferentmix proportions

4.2 Split Tensile Strength

The Split tensile strength characteristics for all the nine mix proportions of the age of 28 days are represented in the fig 2. The split tensile strength of the alkali activated concrete is observed to be decreasing with the increment of fly ash and decrement of ggbs proportions for all A/B ratios. It is seen that the highest split tensile strength was obtained at a activator to binder ratio of 0.55 for 40:60 proportion of fly ash and ggbs.

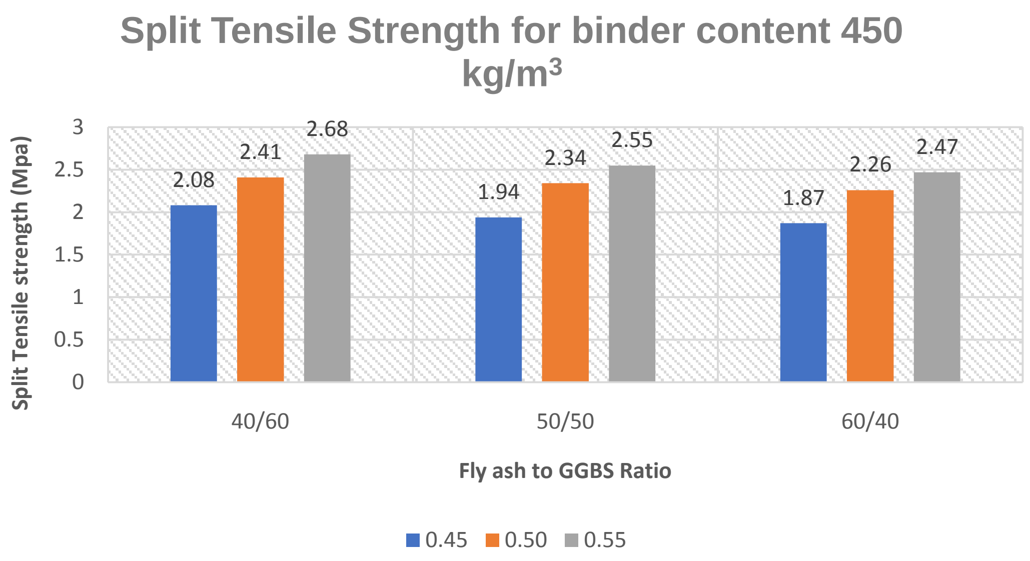

Fig3:Split Tensile Strengthtest for AFSC

4.2 Flexure Strength

The flexure strength characteristics for all the nine mix proportions of the age of 28 days are represented in the fig 2. The flexurestrength of the alkali activated concrete is observed to be decreasing with the increment of fly ash and decrement of ggbs proportions for all A/B ratios. It is seen that the highest compressive strength was obtained at a activator to binder ratio of 0.55 for 40:60 proportion of fly ash and ggbs.

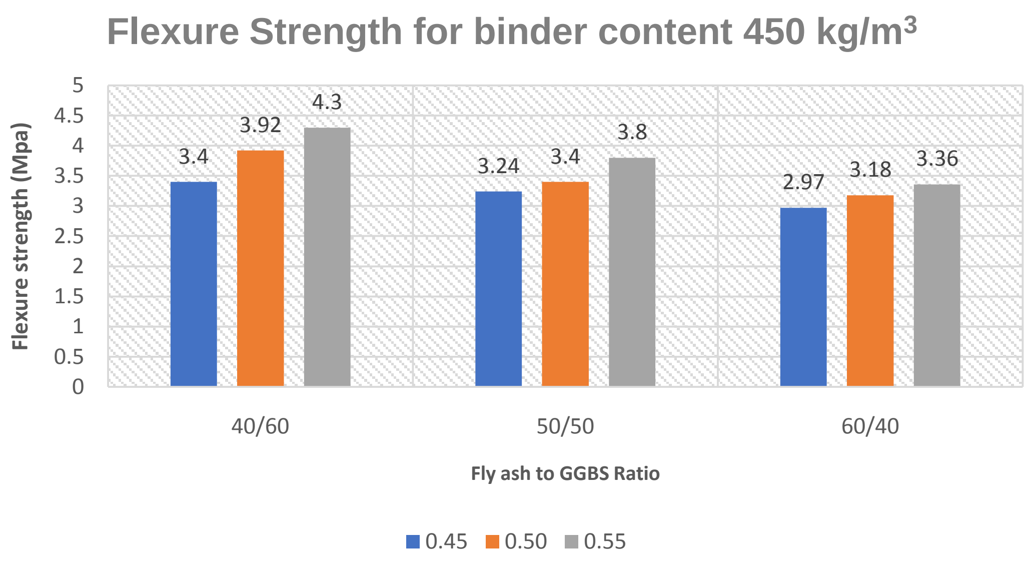

Fig4:Flexure Strengthtest for AFSC

V. CONCLUSIONS

1. The addition of GGBS and fly ash-based geopolymer blends leads to a decrease in both workability and setting time. As the proportion of slag increases, there is a corresponding reduction in the slump of concrete and the flow of mortar.
2. The neutral grade sodium silicate solution gives the better slump and improve the fresh properties of the alkaline activated flyash slag concrete.
3. As the solution/binder ratio rises, the slump values show an increase ranging from 75 to 155 mm. When compared to mixtures featuring 40%, 50% and 60% fly ash replacement, the mixture with a 60%

replacement exhibits higher slump values.

4. As the proportion of ggbs in the binder rises, the compressive strength values exhibit an increase from 20 to 31 MPa. When compared to mixtures featuring 40%, 50% and 60% ggbs replacement, the mixture with a 60% replacement demonstrates higher strength.
5. As the proportion of ggbs in the binder rises, the split tensile strength and flexural strength values increases. When compared to mixtures featuring 40%, 50% and 60% ggbs replacement, the mixture with a 60% replacement demonstrates higher strength.
6. The AFSC demonstrates enhanced performance in terms of both workability and compressive strength, leading to a reduction in environmental impact.

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