# AN EXPERIMENTAL STUDY ON ALKALI ACTIVATED SLAG CONCRETE USING GGBS AND FLYASH

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**Abstract -** *The present paper reports the testing of alkali-activated concrete and a control ordinary Portland cement (OPC) mortar. The main aim is to develop cement less binder activated by sodium silicate. An alkali quality coefficient combining the amounts of main compositions of source materials and sodium oxide ($Na_2O$) in sodium silicate is proposed to assess the properties of alkali activated concrete, based on the hydration mechanism of alkali-activated pastes. Fly ash (FA) and ground granulated blast-furnace slag (GGBS) were employed as source materials. GGBS/Flyash ratios (100/0, 75/ 25, 50/ 50, 25/ 75, and 0/ 100). The ratio of $Na_2O$-to-source material by weight for different mortars ranged between 3% and 5%; as a result, alkali quality coefficient was varied from 1.0 to 1.5. Compressive strength and Flexural strength and Split tensile strength were measured. Test results clearly showed that the compressive strength development of alkali-activated mortar were significantly dependent on the proposed alkali quality coefficient. In particular, a higher rate of compressive strength development achieved at early age for GGBS-based alkali-activated mortar and at long term age for FA-based alkali-activated mortar were comparable to those of OPC mortar.*

***Key Words***: **Sodium hydroxide, Sodium silicate, Fly ash, GGBFS, Compressive strength, Flexural strength, Split tensile strength, sodium oxide dosage, Activator modulus.**

## 1. INTRODUCTION

Concrete is made up of various constituents like cement, aggregates, water, admixtures etc. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement. It is widely known that the production of Ordinary Portland Cement (OPC) consumes considerable energy and at the same time, production of one ton of OPC also releases one ton of $CO_2$ into the atmosphere. Considering the crucial importance of infrastructure development for the Indian economy, it is now believed that using more durable and less energy intensive construction materials is inevitable for the construction industry. Alkali activated slag concretes have attracted much attention as a potential replacement of OPC due to the fact that the production of alkali activated slag concretes cement creates substantially less $CO_2$ emissions. There is no $CO_2$ created in the synthesis of alkali activated slag concretes cured. though some emissions can be attributed to the production of the alkali activator, most notably the alkali silicates. Alkali activated slag concretes also have the potential to be made using industrial waste materials, such as Ground Granulated Blast Furnace Slag (GGBS) further enhancing the environmental credentials. In a political climate where governments around the world are beginning to tax $CO_2$ emissions and promote sustainable and environmentally friendly materials, alkali activated slag concretes are emerging as an essential material of the future. One of the recent developments in the production of alkali activated slag is the alkali activation of ground granulated blast furnace slag blended with Flyash (FA). Huge volumes of flyash are generated around the world. Most of the fly ash is not effectively used, and a large proportion of it is disposed off in landfills. As the need for power increases, the volume of fly ash produced will increase. The present study focuses on strength properties of alkali activated GGBS-FA concrete mixes made with coarse aggregate for rigid pavements. GGBS is a byproduct from the iron-making industries along with fly ash from thermal power plants which serve as binder. This type of concrete caters the need of conservation of natural resources and also helps to tackle the problems related to the disposal of Fly ash. Since, this kind of concrete is air curing; it can be of great benefit especially in arid and desert regions, which suffer from severe scarcity of water resources. There is also saving in electricity as there is no necessity of thermal curing. It becomes a more environmentally friendly material as it decreases the need for depleting raw materials.

## 2. MATERIALS

### 2.1 Ground Granulated Blast-Furnace Slag (GGBS).

Blast furnace slag is the most widely investigated and probably the most effective cement replacement material used in concrete. Blast furnace slag is a by-product obtained from the iron industry. It is non-metallic hydraulic material consisting essentially of calcium silicates and aluminosilicates of calcium developed in a molten state condition simultaneously with iron in blast furnace. For the present investigation, GGBS manufactured by JSW Iron and Steel Company, was procured from a local supplier. The chemical composition and physical the present investigation is presented in Table 1.

**Table 1.Chemical and Physical properties of GGBS**

| Constituent | Weight (%) |
|---|---|
| CaO | 37.34 |
| $Al_2O_3$ | 14.42 |
| $Fe_2O_3$ | 1.11 |
| $SiO_2$ | 37.73 |
| MgO | 8.71 |
| $Na_2O$ | 0.16 |
| $K_2O$ | 0.07 |
| $SO_3$ | 0.39 |
| Insoluble residue | 1.59 |
| Loss of ignition | 0.24 |
| Glass content | 92% |
| Fineness (m2/kg) | 370 |
| Specific gravity | 2.9 |

### 2.2 Flyash (FA)

Flyash is a by-product obtained from coal burning from electric power plants. Flashes are classified as per ASTM C 618:93 as either class F or class C. Class F fly ash has pozzolanic properties and Class C fly ash has pozzolanic properties as well as cementisious properties. In the present study class Fly ash is used. Fly ash (class F) procured from Vijayawada Thermal Power Plant (VTPS), Vijayawada was used for the present investigation. The chemical and physical property of Flyash conforming the requirements of IS 3812 Part I & II (2003) are reported below in Table 2.

**Table 2.Chemical and Physical properties of Flyash**

| Chemical properties | Composition (%) | Requirements as per IS 3812(part-2)2003 |
|---|---|---|
| $SiO_2$ | 59.75 | 35% min |
| $Al_2O_3$ | 26.06 | $SiO_2$+ $Al_2O3$+ $Fe_2O_3$ Combined 70% max |
| $Fe_2O_3$ | 6.73 | |
| CaO | 3.05 | 5% max |
| $Na_2O$ | 0.93 | Total alkalis 5% max |
| $K_2O$ | 1.54 | |
| $SO_3$ | 0.65 | 2.75% max |
| Loss of Ignition | 1.26 | 12% max |
| Fineness (m2/kg) | 350 | 320 |
| Specific Gravity | 2.2 | - |

### 2.3 Fine Aggregates

In the present investigation locally available river sand conforming to Zone II of IS: 393-1970 was used as fine aggregates. The river sand was tested according to IS: 2386 (Part I-IV)-1963.Properties are given in Table 3.

**Table 3.Physical Properties Of Fine Aggregate**

| Sl. No. | Property | Value Obtained |
|---|---|---|
| 1. | Specific gravity | 2.66 |
| 2. | Fineness modulus | 2.51 |
| 3. | Grading Zone | Zone II |

### 2.4 Coarse Aggregates

Crushed granite aggregates of maximum size 20 mm (20mm to 4.75min) conforming to IS: 383-1970 was used for the present investigation. The physical properties and sieve analysis data of natural coarse aggregates are evaluated as per IS:2386 (Part 1-1V)-1963. Properties are given in Table 4.

**Table 4.Physical Properties Of Coarse Aggregate**

| Sl. No. | Property | Value Obtained |
|---|---|---|
| 1. | Type | Crushed |
| 2. | Specific gravity | 2.8 |
| 3. | Fineness modulus | 7.56 |

### 2.5 Water

Potable tap water available in the institute laboratory was used for casting of all specimens and for the curing of OPC based concrete specimens in the present investigation. The same water was utilized for the preparation of alkaline activator solution.

## 3. Alkaline Activators

The mixture f sodium hydroxide (NaOH) and sodium silicate have proved to deliver the best performance in alkali activated binders. Hence in the present investigation, a combination of sodium hydroxide and liquid sodium silicate is used as the alkaline activator. Commercial grade sodium hydroxide flakes 98% purity and liquid sodium silicate were procured from local supplier. The liquid sodium silicate was tested as IS: 142112-1995 for the physical properties and the results is presented in Table 5 and 6. The physical properties of sodium hydroxide and for the present investigation are presented in Table. The alkaline activator solution was prepared was dissolving the sodium hydroxide flakes in sodium silicate solution in proper proportion in order to achieve the desired activator modulus ($Ms=SiO_2/Na_2O$) and desired sodium oxide dosage. The solution was stirred properly and laboratory water was added in order to bring the solution to contain total water content equivalent to water/binder (w/c) 0.4 of total binder content. The solution was stored in tight plastic container at least one day prior to mixing. The solution was brought to the desired total water content by mixing extra water during the time of casting of specimen.

| Parameter | Levels | | |
|---|---|---|---|
| | Low | Medium | High |
| Sodium oxide dosage (%) | 3 | 4 | 5 |
| Activator modulus(Ms) | 1.0 | 1.25 | 1.5 |

**Table 5.Properties of Sodium Silicate solution**

| Constituent | Percentage (%) |
|---|---|
| $Na_2O$ % (by weight) | 14.7 |
| $SiO_2$ % (by weight) | 32.8 |
| Water % (by weight) | 52.5 |
| % of solids (by weight) | 47.5 |
| Ms ($SiO_2/Na_2O$) | 2.23 |
| Specific Gravity | 1.57 |

**Table 6.Properties of Sodium Hydroxide (97% purity)**

| | |
|---|---|
| Molecular formula | NaOH |
| Molar mass | 39.9971 g/mol |
| Appearance | White solid |
| Specific Gravity | 2.1 |
| Solubility in water | 114 g/100ml (250C) |

## 4. Concrete mix design

The mix design for OPC concrete is based on the procedure suggested by IS: 10262-2009. The total binder content is restricted to 425 kg/m3, with water/binder ratio of 0.4. The mixes are designed to achieve a slump value of 25-50mm.The AASC mixes are proportioned to contain same binder content (425 kg/m3) and water/binder ratio (0.4) as that of OPCC mix. The AASC were prepared by varying the fly ash content 0 to 100%, activator modulus 1.0 to 1.5 and sodium oxide 3 to 5%. The total water content in the activator solution for AASC mixes constituted the sum of water readily available in liquid sodium silicate solution plus the extra water added, to arrive at the required water/binder ratio. The alkali activator were proportioned to provide desired dosage of $Na_2O$ (by weight of binder), with an optimal activator modulus (Ms) and selected total water/binder ratio. No super-plasticizers are added for AASC mixes. AASC mixes were prepared with natural coarse aggregate. The aggregates used were in saturated surface dry condition. The details of AASC mixes for given combinations are listed in below Tables.

**Mix Proportions**

| Sl.No. | GGBS+Flyash In (%) | Group-1 | |
|---|---|---|---|
| | | Activator Modulus(Ms) | $Na_2O$ in (%) |
| A | 100+0 | 1 | 3 |
| B | 75+25 | 1 | 3 |
| C | 50+50 | 1 | 3 |
| D | 25+75 | 1 | 3 |
| E | 0+100 | 1 | 3 |

| Sl.No. | GGBS+Flyash In (%) | Group-2 | |
|---|---|---|---|
| | | Activator Modulus(Ms) | $Na_2O$ in (%) |
| A | 100+0 | 1.25 | 4 |
| B | 75+25 | 1.25 | 4 |
| C | 50+50 | 1.25 | 4 |
| D | 25+75 | 1.25 | 4 |
| E | 0+100 | 1.25 | 4 |

| Sl.No. | GGBS+Flyash In (%) | Group-3 | |
|---|---|---|---|
| | | Activator Modulus(Ms) | Na2O in (%) |
| A | 100+0 | 1.5 | 5 |
| B | 75+25 | 1.5 | 5 |
| C | 50+50 | 1.5 | 5 |
| D | 25+75 | 1.5 | 5 |
| E | 0+100 | 1.5 | 5 |

**Specimen details for various tests**

| Sl. No | Types of test | Specimen type | Specimen dimension(mm) |
|---|---|---|---|
| 1 | Cube Compression | Cube | 150X150X150 |
| 2 | four-point flexure | Beam | 100X100X500 |
| 3 | split tensile strength | Cylinder | 150(dia)X300(height) |

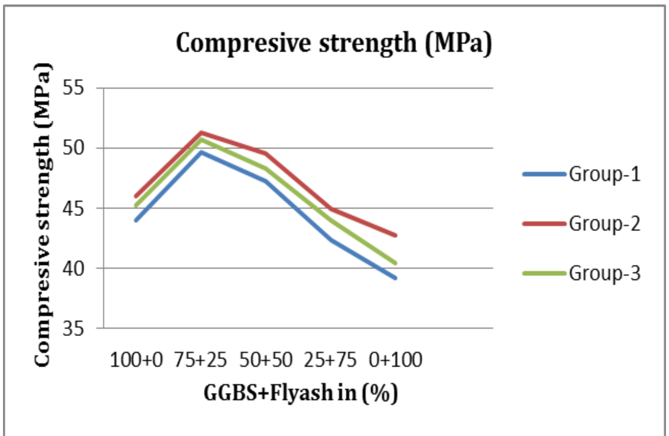
## 5. RESULTS AND DISCUSSIONS

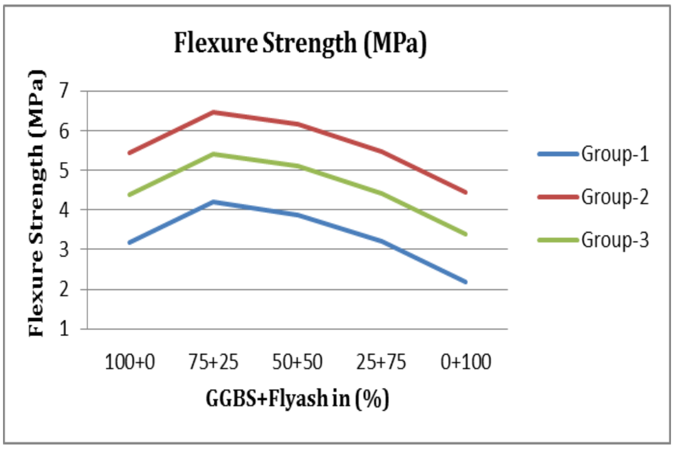
In this chapter, the observations made on the properties of AASC mixes discussed for the given combinations. This is followed by a detailed discussion on the strength related properties of AASC mixes like compressive strength, flexural and split tensile strength.

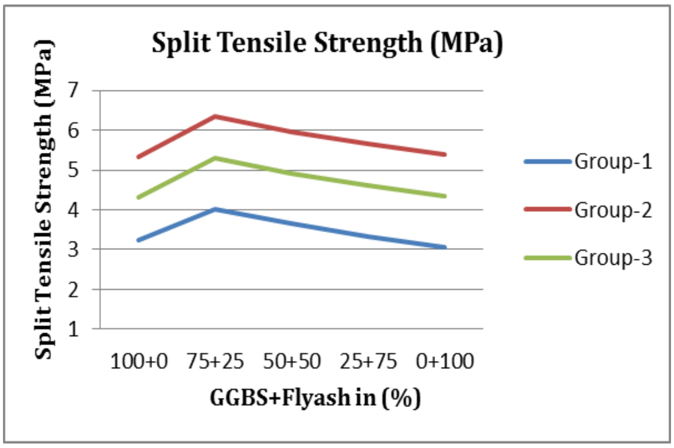
| Sl.No. | Group-1 | | | |
|---|---|---|---|---|
| | GGBS+Flyash In (%) | Compressive Strength(MPa) | Flexure Strength (MPa) | Split Tensile Strength (MPa) |
| a | 100+0 | 44 | 3.17 | 3.25 |
| b | 75+25 | 49.63 | 4.2 | 4.01 |
| c | 50+50 | 47.27 | 3.87 | 3.67 |
| d | 25+75 | 42.34 | 3.22 | 3.33 |
| e | 0+100 | 39.17 | 2.17 | 3.05 |

| Sl.No. | Group-2 | | | |
|---|---|---|---|---|
| | GGBS+Flyash In (%) | Compressive Strength(MPa) | Flexure Strength (MPa) | Split Tensile Strength (MPa) |
| a | 100+0 | 46.03 | 5.45 | 5.34 |
| b | 75+25 | 51.32 | 6.46 | 6.34 |
| c | 50+50 | 49.59 | 6.17 | 5.95 |
| d | 25+75 | 44.98 | 5.46 | 5.65 |
| e | 0+100 | 42.72 | 4.44 | 5.38 |

| Sl.No. | Group-3 | | | |
|---|---|---|---|---|
| | GGBS+Flyash In (%) | Compressive Strength(MPa) | Flexure Strength (MPa) | Split Tensile Strength (MPa) |
| A | 100+0 | 45.24 | 4.39 | 4.3 |
| B | 75+25 | 50.67 | 5.4 | 5.3 |
| C | 50+50 | 48.28 | 5.11 | 4.91 |
| D | 25+75 | 43.95 | 4.4 | 4.61 |
| E | 0+100 | 40.44 | 3.38 | 4.34 |




## 6. CONCLUSIONS

The following are some of the conclusion drawn from the present investigation:

- The strength properties of AASC are influenced widely by the modulus and the sodium oxide dosage of the alkaline solutions. The use activator modulus of 1.25 in the alkaline activator provided the highest compressive strength for AASC with Flyash zero percent and AASC mixes with fly ash 25%.
- The compressive strength, flexural strength and split tensile strength value increases with increase in sodium oxide dosage.
- The compressive strength value decreases with increase in fly ash contents, when fly ash used above 50%
- The strength of the AASC depends on the sodium oxide dosage of the alkaline activator. Higher the sodium oxide dosage, higher the strength achieved.
- The strength of the AASC mixes decreased with the increased FA content.

AASC concrete will result in the reduction of OPC and in turn reduces carbon dioxide emissions

## REFERENCES

[1] Bkharev, T., Sanjayan, J.G., and Cheng, Y.B. (1999). Alkali Activation of Australian Slag Cements. Cement and Concrete Research, 29(1), pp-113-120.

[2] Chang, J.J. (2003). A Study on the Setting Characteristics of Sodium Silicate Activated Slag pastes. Cement and Concrete research, 33(7), 1005-1011.

[3] Chi, M. (2012). Effects of Dosage of Alkali Activated Solution and Curing Conditions on the Properties and Durability of Alkali Activated Slag Concrete. Construction and Building Materisla, 35, 240-245.

[4] Chindaprasirt, P., Chareerat T., Hatanaka, S., and Cao, T.,. (2011). High strength Geopolymer Using Fine High-Calcium Fly Ash. Journal of Material in Civil Engineering ASCE,23(3) , 264-270.

[5] Deepak, R., Sulapha, P., and Narayanan, N.,. (2010). Structure and Strength of NAOH Activated Concretes Containing Fly ash or GGBFS as the sole Binder. Cement & Concrete Composites, 32(6), 399-410.

[6] Fernandez-Jimenez,A., and Puertas, F. (2001). "Setting of Alkali Activated Slag Cement-Influence of activator nature". Advance Cement Research, 13(3), 115-121.

[7] Naidu, G., Prasad, A.S.S.N., Adiseshu, S., and Satyanarayana, P.V. (2012). "A Study on Strength Properties of Geopolymer Concrete with Adition of G.G.B.S". International Journal of Engineering Research and Development, 2(4) , 19-28.

[8] Puetas, F., Martinez-Rairez, S., Alonso, S., and Vazquez, T. (2000). "Alkali Activated Fly Ash/ Slag Cements: Strength Behaviour and Hydration Products". Cement and Concrete Research, 30(10), 1625-1632.

[9] Wang, S.D.., Pu, X.C., Scrivener, K.L., and Pratt, P.L. (1994). "Factors affecting the Strength of Alkali Activated Slag ". Cement and Concrete Research,24(6) , 1033-1043.

[10] Xiaolu, G., Huisheng, S., and Warren, A.D. (2010). "Compressive Strength and Microstructural Characteristics of Class C Fly Ash Geopolymer". Cement &Concrete Composites, 32(2), 142-147.

[11] Yang Yang, K., Song, J., Lee, E., and Ashrour, A.F. (2008). "Properties of Cementless Mortor Activated By Sodium Silicate". Construction and Building Materials, 22 , 1981-1989.