Behaviour of alkali activated concrete under marine conditions

P Saravanakumar\textsuperscript{1} and P Kalaivani\textsuperscript{2}

\textsuperscript{1}Department of Civil Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, India.
\textsuperscript{2}SRM Institute of Science and Technology, Ramapuram Campus, Chennai, India.

Email: psaravana2000@gmail.com

Abstract: This study aims to investigate the mechanical and durability behavior of flyash and slag based alkali activated concrete mixes under marine conditions. To fulfil the aim of this study, various tests such as Compressive Strength test, Sorptivity test, Half Cell Potential test and Alkalinity tests were done on both flyash and slag based alkali activated concrete. The experimental results showed that the alkali activated concrete attains its strength at earlier stages when compared to control concrete and it also has low sorptivity value which influences much indurability under marine conditions. Though it was cured in acidic environment for four weeks the alkali activated concrete samples showed only intermediate risk of corrosion.

1. INTRODUCTION

In 1987, the United Nations Brundtland Commission defined as sustainable development shall meet the needs of the present without compromising ability of future generation to meets their own needs. It also showed that development that going to be made to sustain the planetary resources by using them effectively without making unnecessary wastage. Cement is extensively used as a binding material in the construction industry. This has led to increased pollution levels in the environment and hence use of various industrial by-products such as flyash, slag, etc. is being considered as alternatives for cement.

Alkali Activated Slag (AAS) binders have higher advantage among the alternative materials due to its simple manufacturing process. It also have significant benefits of lower energy requirement and reducing the greenhouse gas emission with respect to manufacturing of Portland cement. Several studies [1-3] indicate that AAS cements and concretes present high mechanical and durability strength. They showed good performance against chemical attack, freeze-thaw cycles and high temperatures. Fly ash based geopolymer/aggregate composites have superior performance compared to OPC concrete in certain areas such as resistance to sulphate attacks [4]. It was reported that the increase in mineral admixtures such as flyash, slag content influenced in the water absorption and the strength of the concrete in the positive way. It reduced the water absorption and improve the strength of the concrete [5,6].

The performance of geopolymers depends upon various factors like the characteristics of waste materials from which they are refined, proportion of alumino-silicates, type of activator solution used, concentration of the activator solution, curing regimes etc.
In this study the performance of flyash and GGBFS based Alkali Activated Concrete (AAC) concrete in Marine environment were studied and compared with control concrete. For this study strength and durability characteristics such as compressive strength, capillary absorption (sorptivity) test, corrosion test (Half Cell Potential) and Alkalinity tests were done for all mixes and the results were compared with control concrete.

2. EXPERIMENTAL INVESTIGATION

2.1. Materials
GGBFS and Flyash were tested and the chemical composition and physical properties were presented in Table 1 and Table 2. The basicity coefficient has been computed as 0.98 (less than 1), which categorizes the GGBS used as acidic and best suited as a starting material for alkali activated slag binder. In addition, the ratio CaO/SiO2 is 1.18 (0.5 to 2.0), Al2O3/SiO2 is 0.56 (0.1 to 0.6) and hydration modulus is 2.04 (greater than 1.4) which makes GGBS best suited for binder. Low calcium Flyash (Class F) with specific gravity 2.64 procured from Mettur thermal power plant, India was used as the main source material.

The well graded coarse aggregate of 12.5 mm size with specific gravity 2.83 confirming to IS 383-1970 was used. To improve the workability of GPC, superplasticizer (based on Naphthalene Sulphonate) was used as admixture confirming to IS 9103:1999.

| Table 1. Chemical composition of Cementitious materials |
|---------------------------------|
| Oxide | CaO | SiO2 | Al2O3 | MgO | SO3 | Fe2O3 | Na2O | K2O |
|-------|-----|------|-------|-----|-----|-------|------|-----|
| OPC (%) | 63.12 | 24.52 | 6.88 | 2.16 | 1.43 | 0.51 | 0.44 | 0.63 |
| GGBFS (%) | 36.77 | 30.97 | 17.41 | 9.01 | 1.82 | 1.03 | 0.69 | 0.46 |
| Flyash (%) | 2.07 | 63.60 | 25.71 | 0.42 | 0.18 | 3.97 | 0.16 | 1.02 |

| Table 2. Physical properties of Flyash and Slag |
|---------------------------------|
| Property | Slag | Flyash |
|-------|------|-------|
| Specific Gravity | 2.9 | 2.64 |
| Fineness, m²/kg | 438 | 430 |
| Bulk density, kg/m³ | 1231 | 1045 |

2.2. Alkaline solution
Sodium hydroxide was first mixed with distilled water. Sodium hydroxide solution of 10M was prepared a day before casting and kept in room temperature in order to avoid rapid setting of geopolymeric reactions due to excessive heat evolved. This solution was then mixed with sodium silicate at an alkaline ratio of 2 with the liquid binder ratio of 0.5 to produce the alkali activator solution. The alkali activator solutions were then used in the preparation of geopolymer (GGBS) mixes. Specimens for different mix ratios were cast as per Indian standard code and testing was done after ambient curing period of 7 days and 28 days to study the effect of age of concrete. All the cast specimens were removed from the mould after 48 hours. The curing was done in saline water.

2.3. Experiments and Specimen Details
To study the compressive strength of the concrete 150 mm size cubes were cast. The test was conducted using digital compression testing machine of 3000 kN capacity as per BS1881 standard. The rate of loading applied for compressive strength tests were 200 kN/min. Concrete specimens were compacted with the help of a table vibrator. The durability characteristics such as sorptivity, and corrosion resistance were also studied as per ASTM standards. Cylinder specimens of size 100 mm diameter and 50 mm height were prepared by cutting the top and bottom of the 100 mm x 200 mm cylinder specimen for sorptivity test. To study the corrosion resistance through Half cell potential test,
cylinder specimens 100 mm φ and 200 mm height were cast. Minimum three specimens were cast for all ages in each mix series and the average values were taken to assess the specimen characteristics.

3. RESULTS AND DISCUSSION

3.1. Compressive strength of AAC concrete
From Figure 1, it is observed that initial strength acquired by both flyash and slag based alkali activated concrete are high when compared to control concrete. This is because AAC concrete gains strength rapidly even in 7 days of casting and increase in strength after the initial period become stable for the remaining days. On a comparative study, slag based AAC concrete showed better result than flyash based AAC concrete. This is because finer particles present in Slag are comparatively higher, hence leading to better density and ultimately high strength. Addition of mineral admixtures such as flyash, slag improved the strength properties at ambient temperature. The presence of higher content of fines in slag reduced the void space in the matrix, thus improving the compressive strength. The calcium and alumina in Fly ash and GGBFS improved the bonding system [7].

![Figure 1. Compressive Strength of Concrete mixes](image)

3.2. Alkalinity of AAC Concrete
The concrete degradation level was measured through the alkalinity test. The measure of pH indicates the deteriorated condition of the concrete. The good conditioned concrete exhibits the pH value of 12 to 14. Up to the pH value of 9 was permitted. Below the pH value of 9 represented the severe degradation of the concrete structure. As the pH is lowered, the bonding capability of cement gets lowered and the corrosion gets initiated. The pH value for the different AAC mixtures were examined from the 28 days strength tested concrete samples and the results were presented in the Table 3. Since all the concrete mixtures have the pH range of 11 to 14 it was concluded that the possibility of corrosion was low and more durable.

| Samples             | Initial | 24hrs | 48hrs | 72hrs |
|---------------------|---------|-------|-------|-------|
| Control Concrete    | 11.5    | 12    | 12    | 12    |
| Slag based AAC      | 12.6    | 12.8  | 13    | 13    |
| Flyash based AAC    | 12.6    | 12.6  | 13.4  | 13.4  |

3.3. Sorptivity of AAC Concrete
The rate of capillary suction of hardened concrete was measured through water sorptivity testing as per ASTM C1585. This reflects the micro structural properties of hardened concrete’s capacity for capillary suction. The absorption rate was computed for both flyash and GGBFS based AAC concrete...
mix and it was compared with control concrete (Figure 2). Then readings are taken periodically till the weight become constant. From the readings, it is found that weight of the specimen started increasing slowly, after three hours there is no change in mass is noted. The initial 3 hours readings were plotted and the slope of the best fit line having $r^2$ values not less than 0.9 were drawn to compute the sorptivity value for all concrete mixtures. Irrespective of the mix group the rate of water absorption was increased with the square root of time. The readings showed that about 20-30gms of the weight of the specimens increased in three hour duration. This increase in weight is only due to the absorption of water through capillary action. The rate of absorption for flyash based geopolymer concrete and slag based geopolymer concrete are lower than control concrete. Slag and flyash have fine particles which form a denser medium and hence lesser porosity than control concrete was absorbed [8, 9, 10].

![Figure 2. Sorptivity of concrete mixes](image)

3.4. Half Cell Potential
The experimental observations showed that the specimen was corroded lightly due to curing of specimens in saline water for 28 days. The initial weight of the specimens was also taken. Then the samples were immersed in HCl acid of normality of 0.25N. The readings were taken at an interval of one week for 28 days and the risk of corrosion were estimated and showed in Table 4. For the first three week there was no risk of corrosion were found in any of the specimen samples. After the third week it was found that the risk of corrosion in slag based geopolymer concrete showed lower risk and flyash based geopolymer concrete showed the intermediate risk of corrosion. From this we concluded that the slag based AAC concrete showed better resistance against risk of corrosion than flyash based AAC concrete. In general both flyash and slag based AAC concrete showed better resistance against corrosion effects [11].

![Table 4. Corrosion measurement for Concrete mixes](table)

| Type of concrete | Age of Concrete in days | Half Cell Potential (mv) | Weight (kg) | Calamal Electrode (mV) | Corrosion Condition |
|------------------|-------------------------|--------------------------|-------------|------------------------|---------------------|
|                  | Specimen Number         | Specimen Number          | Specimen Number | Specimen Number | Specimen Number |
| Control Concrete | 7                       | -62                      | -71          | -67                    | 1.262 1.166 1.206 | >126 >126 >126 | Low Risk |
|                  | 14                      | -81                      | -101         | -98                    | 1.172 1.208 1.214 | >126 >126 >126 | Low Risk |
|                  | 21                      | -112                     | -126         | 118                    | 1.166 1.168 1.202 | >126 >126 >126 | Low Risk |
|                  | 28                      | -178                     | -196         | -188                   | 1.314 1.202 1.205 | 126 126 126  | Intermediate |
| Flyash based AAC concrete | 7                       | -57                      | -61          | -67                    | 1.214 1.206 1.206 | >126 >126 >126 | Low Risk |
|                  | 14                      | -82                      | -99          | -73                    | 1.214 1.12 1.16   | >126 >126 >126 | Low Risk |
|                  | 21                      | -115                     | -122         | -109                   | 1.21 1.206 1.206  | >126 >126 >126 | Low Risk |
|                  | 28                      | -185                     | -191         | -179                   | 1.21 1.202 1.162  | 126 126 126  | Intermediate |
4. CONCLUSION

From the test results following conclusions have been made:

1. Little difference was found in the workability of flyash based geopolymer concrete and slag based geopolymer concrete with respect to control concrete, but they are well fitted with the medium workability limit.

2. AAC concrete attains its strength at the higher rate in the initial stage when compared to control concrete. The Slag based AAC concrete attained the strength faster than flyash based AAC concrete.

3. The pH value ranges from 12-14 for both flyash and Slag based AAC mixes which was well below the acidic medium and hence it denotes low alkalinity.

4. The rate of capillary adsorption for both flyash and slag based AAC concrete were lower than control concrete.

5. Although the samples are cured in HCl for four weeks under the normality of 0.25 both the flyash and Slag based AAC concretes showed low risk of corrosion when compared to control concrete.

6. To be more specific slag based AAC concrete showed lesser corrosion when compared to flyash based AAC concrete.

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