

STRENGTH BEHAVIOR OF SLAG (GGBS) BASED GEOPOLYMER CONCRETE IN CHLORIDE ENVIRONMENT

S. Sarker*, M. A. Hossain, O. C. Debnath, N. Tabassum & M. S. Islam

*Department of Civil Engineering, Chittagong University of Engineering and Technology, Chittagong,
Bangladesh*

**Corresponding Author: sarkercuet11@gmail.com*

ABSTRACT

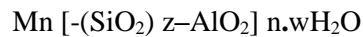
Concrete is the most abundantly used manmade material in the world. The main component of concrete is the Ordinary Portland Cement (OPC) which is the second most utilized material after water. After automobile, OPC production is the second major generator of carbon-dioxide which pollutes the atmosphere. Geopolymer has been widely used as a cement replacement material which leads to reduce the carbon dioxide emission by using the industrial by-product as a base material. Ground Granulated Blast Furnace Slag (GGBS) is a latent hydraulic material that can directly react with water in presence of an alkali activator. After activation, GGBS in alkali activator solution is termed as alkali activated slag (AAS) and act as the main constituent of geopolymer. This paper focuses on experimental results of a study conducted to assess the strength of AAS concrete over 7, 14, 28 & 60 days exposure in normal & sodium chloride environment. This programme covers the immersion of cubical specimen in NaCl solution of different concentration. The performance of the specimen was evaluated in terms of visual appearance, change in weight & compressive strength over the stated exposure periods. From this study, it is observed that the strength of geopolymer concrete specimens increase with the increase of dosages & ages in normal environment while in chloride environment, the corresponding gain in strength is observed to be lower as compared to normal environment.

Keywords: Geopolymer; GGBS; alkali activators; strength; chloride environment

INTRODUCTION

Concrete is the most widely used construction material due to its versatility and energy efficient next to steel and aluminium (Hardjito et al., 2004). The main component of concrete is the ordinary Portland cement (OPC) which is conveniently used as the binder in concrete still now. But the production of OPC is a concerning issue for the environment now a days. In the production of OPC, carbon dioxide gas is produced which is the main source of greenhouse gas and global warming. Statistics shows that the amount of carbon dioxide production is almost one ton for every ton of OPC produced. Alarming issue is that, this carbon dioxide contributes to greenhouse gas emission approx. 7% of the total greenhouse gas (GHG) emission to the earth's atmosphere. Among the GHGs CO₂ contributes 65% of the total global warming. It can be seen that even a small reduction of greenhouse gas emissions per ton of manufactured concrete can make a significant impact on environment (Flower and Sanjayan, 2007). Each year the concrete industry produced almost 12 billion tons of concrete (Attwir and Kabir, 2010) globally and utilized 1.65 billion tons of cement for that purpose. Production of 1 ton of cement requires around 2.8 tons of raw materials including fuel as reported on four different studies (Björk, 1999; Reddy et al., 2010; Anuar et al., 2011; Guo et al., 2010). The increase of cement production is reported to be almost 3% per year. Geopolymers are inorganic polymeric binding materials, firstly developed by Joseph Davidovits in 1970s. Geopolymerisation involves a chemical reaction between an aluminosilicate (Al-Si) material and a strong alkaline solution yielding amorphous to semi crystalline three-dimensional polymeric structures, which consist of Si-O-Al bonds. In 1978, Davidovits proposed that an Al-Si compound could polymerise with an alkaline solution. Davidovits (1988) discovered that the concrete used in ancient structures is alkali-activated aluminosilicate binders and named it as geopolymer concrete because of polymerization reaction. This led to the idea of cement replacement and the

subsequent creation of “Geopolymer Concrete”. Geopolymer is a type of amorphous aluminohydroxide product that exhibits the ideal properties of rock-forming elements, i.e., hardness, chemical stability and longevity. Geopolymer binders are used together with aggregates to produce geopolymer concretes which are ideal for building and repairing infrastructures and for precasting units because they have very high early strength. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows (Davidovits 1999):



Where: M = the alkaline element or cation such as potassium, sodium or calcium; the symbol – indicates the presence of a bond, n is the degree of polycondensation or polymerisation; z is 1, 2, 3, or higher, up to 32.

The chemical reaction may comprise the following steps (Davidovits 1999; Xu and van Deventer 2000):

1. Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
2. Transportation or orientation or condensation of precursor ions into monomers.
3. Setting or polycondensation/polymerisation of monomers into polymeric structures.

However, these three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately (Palomo et al. 1999).

The main objective of this study is to evaluate the strength, durability and suitability of Slag (GGBS) based geopolymer concrete as an alternative of conventional concrete. However, the specific objectives are listed as follows:

- ▶ To optimize the mix design for AAS (alkali activated slag) concrete.
- ▶ To evaluate the compressive strength of AAS concrete at different age.
- ▶ To evaluate the performance of AAS concrete in Chloride environment compared to normal environment.

METHODOLOGY

The following articles discuss the materials and methodologies used for the study.

Materials and Sample Preparation

Slag sample used for this study was collected from Royal Cement Company, Chittagong (Bangladesh). Table-1 shows the chemical properties of slag used for the experiment.

Table 1: Chemical Composition of GGBS (% mass)

Composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	CaO	MgO	Na ₂ O	K ₂ O	LOI
GGBS	29.27	17.07	1.76	0.49	40.07	8.35	0.61	0.23	0.06

*LOI- loss of ignition

Combined Aggregate:

Combined aggregate means the mixture of fine aggregate (43%) & coarse aggregate (57%). Fine aggregate were collected from locally available source. Fine aggregate & coarse aggregate were prepared in accordance with ASTM C778-02 & ASTM C33-03 respectively. The grading & material properties of coarse & fine aggregate are shown in the Table-2 & Table-3.

Table 2: Grading of Combined Aggregate

Coarse Aggregate	Sieve size(mm)	Passing	Retain	%
		19	12.5	19.95
		12.5	9.5	17.1
	9.5	4.75	19.95	
Coarse aggregate=57%				
Fine Aggregate			43%	

Total combined aggregate=100%

Table 3: Properties of Aggregates

	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.52	2.67
Absorption Capacity	1.45(%)	0.8(%)
Moisture Content	1.25(%)	0.57(%)
Fineness Modulus	2.57	NA
Unit Weight (kg/m ³)	1580	1560

Alkaline Activators:

The alkali activators used in this study is a sodium silicate based solution which is a mixture of sodium silicate (Na_2SiO_3) & sodium hydroxide (NaOH). The NaOH solution was prepared in laboratory by dissolving NaOH pellets in deionized water at least 1 day prior to mixing. 15 molar NaOH solution was used (prepared by dissolving 600g of NaOH per liter of water). The Na_2SiO_3 was collected from local suppliers. Table-4 shows the chemical properties of activator solution.

Table 4: Chemical properties of activator solution

Components	Na_2O	SiO_2	H_2O	Molarity(M)
Na_2SiO_3	8%	26%	66%	NA
NaOH	29.05%	0%	70.95%	15

EXPERIMENTAL PROGRAMME

Mix Design:

The combined solution of sodium silicate (Na_2SiO_3) and NaOH solution was used as alkaline activators. Two dosage of Na_2O (% Na_2O) was selected for experiment those were 5% & 7% respectively which was the ratio of Na_2O content of alkaline solution to GGBS. Two activator modulus having 1.0 and 1.5 respectively was selected for this experiment which is the mass ratio of SiO_2 to Na_2O . The alkaline activator was prepared by mixing a sodium silicate and NaOH solution with a concentration of 15 M. Specimen notation used for alkali activated slag concrete is given in Fig.1

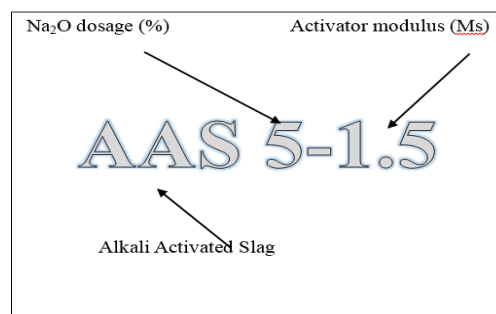


Fig. 1: Specification notation for AAS concrete specimen

Mix Details:

The mass ratio of combined aggregate to slag was fixed at 3 for all batches. A water binder ratio of 0.45 was used & kept constant for all batches. A total 96 nos. of 100mmX100mmX100mm cubical specimens were prepared for compressive strength test using four mix combination. The variables of AAS concrete are shown in Table-5.

The proportioning of ingredients (binding materials, activator solution, fine sand, coarse aggregate and water) were conducted based on the absolute volume method (Neville, 1996) which assumed that the volume of compacted concrete is equal to the sum of the absolute volume of all the ingredients. The mix proportion for the concrete are given in Table-5

Mixing, moulding and curing:

The sodium hydroxide and sodium silicate solutions are mixed in a plastic container 24 hours before casting. The other ingredients like fine aggregate, coarse aggregate, extra water, and binder (GGBS) were measured in required amount and mixed for 5 minutes. Then the alkaline activator was mixed gradually and the mixture were poured into 100mm cubic moulds and compacted by tamping rod. The curing regime for AAS concrete was 24 hours at room temperature prior to demoulding followed by heat curing continuously at 40°C for 72 hours in temperature controlled room. After completion of heat curing the specimens were kept at room temperature up to the completion of corresponding testing. Various stages of mixing, preparation and curing of AAS concrete specimens are shown in Fig.2 – Fig.6.

Table 5: AAS concrete mixes and variables

Mix	Variables		Mass of materials (kg/m ³)				
	Na ₂ O Dosage (%)	Activator Modulus (Ms)	GGBS	Combined aggregate	Added water	Na ₂ SiO ₃	NaOH
AAS 5-1.0	5	1.0	537.42	1612	128.19	103.4	64.04
AAS 5-1.5	5	1.5	538.29	1615	104.35	155.3	49.83
AAS 7-1.0	7	1.0	536.32	1609	82.558	144.4	89.48
AAS 7-1.5	7	1.5	537.54	1613	49.128	217.1	69.75



Fig.2: Alkali activator solution



Fig.3: Mixing



Fig.4: Moulding



Fig.5: Demoulding



Fig.6: Heat Curing

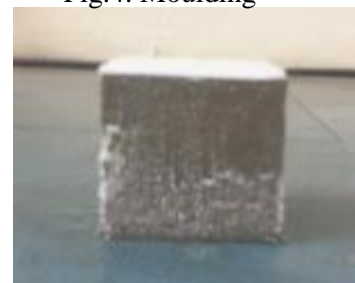


Fig.7: After curing at NaCl solution

Durability Study:

The cubical specimens were submerged in NaCl solution of different concentration i.e. 2^T & 3^T concentration. Sea water contains around 2.78% of NaCl and hence 2^T & 3^T concentration means 5.56% (two times) and 8.34% (three times) NaCl solution. The enhanced salt concentrations were used to get the accelerated effects in short time. For durability study, compressive strength and % weight loss data after 14, 28 & 60 days exposure periods (Fig.7), were studied to evaluate the performance of specimens.

RESULTS AND DISCUSSIONS

The compressive strength gain of AAS concrete having different combination is shown graphically in figure 8. It also shows the compressive strength gain of AAS concrete exposed to NaCl environment of two different concentration. The AAS concrete showed significantly higher strength for the 7% Na₂O compared to the 5% Na₂O. At the age of 60 days, maximum strength for 5% dosage of Na₂O is recorded as 45 Mpa and for 7% dose is 65 MPa. Thus increase of Na₂O that increases the alkalinity of the dosage, increases the strength of the specimens in normal as well as chloride environment. However strength of AAS specimens in chloride environment is observed to be lower than the normal environment for all mix combination. It is also seen that the strength gain in concrete higher dosage of Na₂O is more rapid i.e. in case of AAS 7-1.5, almost 76% of strength is gained after 7 days.

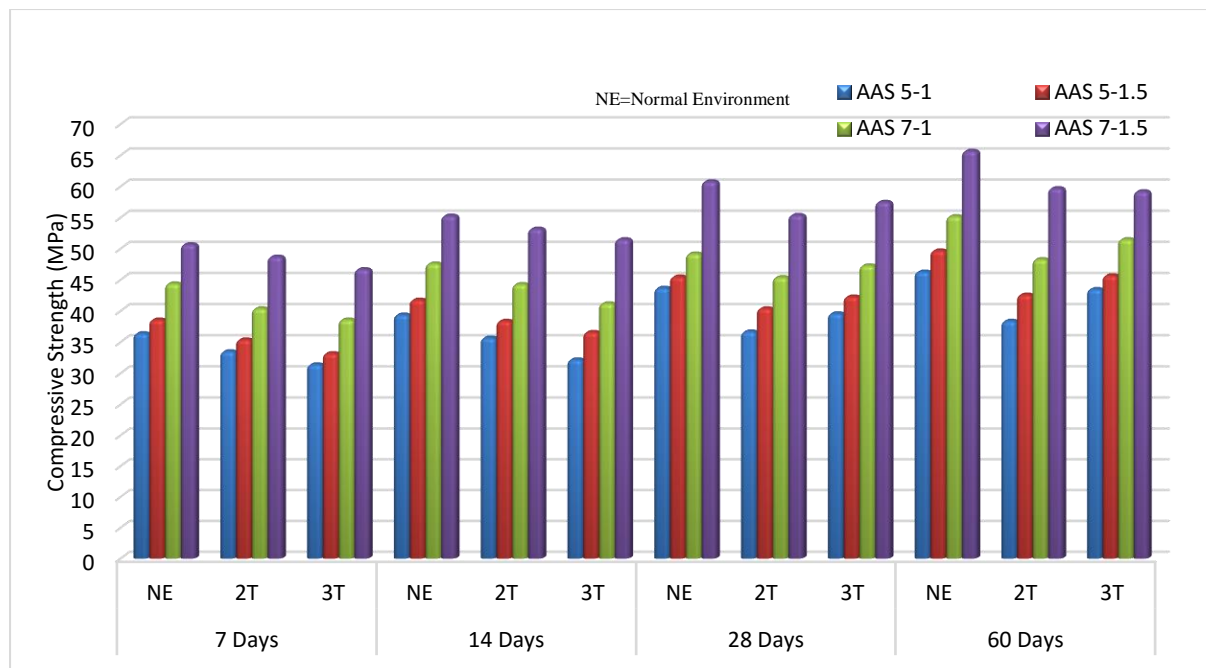


Fig 8: Compressive strength of AAS concrete in normal & chloride environment

The results of weight change for concrete specimens in chloride environment (2^T & 3^T) are presented graphically in Fig.9. The negative value of weight change data indicate the loss of weight due to immersion in NaCl environment which may be associated with surface erosion. After 60 days exposure, it has been seen that the AAS concrete made of higher dosage (7%Na₂O) shows less deterioration & lower weight change. It also indicates the stability of specimen increase with the increase of dosage of Na₂O & activator modulus of alkaline solution. From weight change study it has been seen that the mixed combination AAS 7-1.5 shows relatively better performance as compared to other mixes.

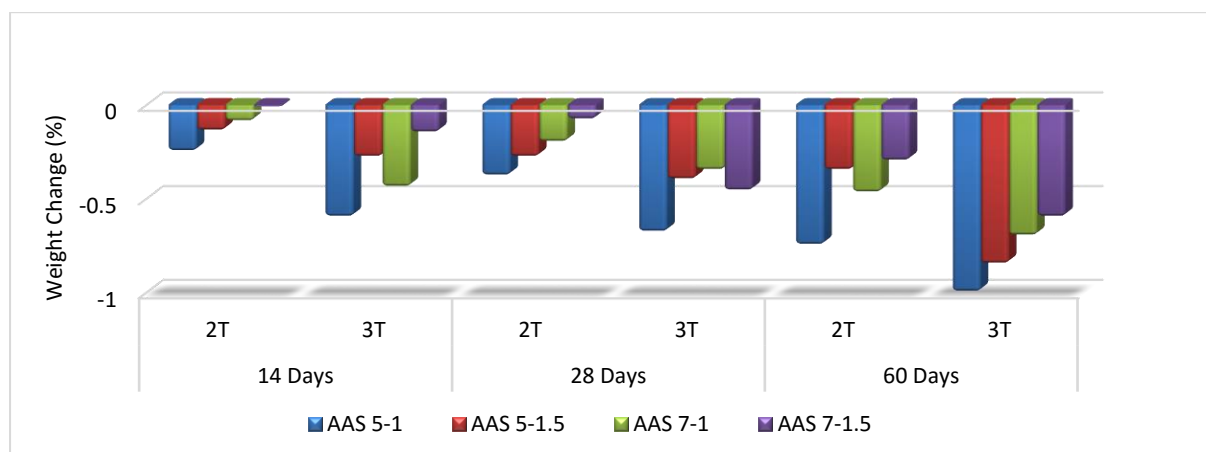


Fig 9: Weight Change (%) of AAS concrete in chloride environment

CONCLUSION:

The followings are the conclusions drawn from the study:

1. AAS 7-1.5 mix attained 50 MPa compressive strength (almost 76% of 60 days) after 7 days which indicates that geopolymer mixes having higher dosage of Na₂O can attain ultimate strength very rapidly.
2. The compressive strength of AAS concrete is observed to increase with the increase of Na₂O dosage & activator modulus.

3. In NaCl environment, AAS concrete showed no noticeable signs of surface degradation, i.e. change of color, sign of cracks/spalls etc. although few signs of salt deposition is noticed at some location of specimen surfaces. It indicates that AAS concrete can offer ample resistance against chloride attack.

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