PLASTICIZED ALKALI ACTIVATED BLAST FURNACE SLAG PASTE

A Thesis submitted to Faculty of Engineering and Technology, Jadavpur University
In partial fulfillment of the requirements for the degree of

MASTER OF CONSTRUCTION ENGINEERING
with specialization in
"STRUCTURAL REPAIR AND RETROFIT ENGINEERING"

By

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This is to certify that the thesis entitled **"Plasticized Alkali Activated Blast Furnace Slag Paste"** submitted by **Pradipta Roychowdhury** (**Examination Roll No: M6CNE1608)** is absolutely based upon his own work under our supervision and neither his thesis nor any part of the thesis has been submitted for any degree/diploma or any other academic award anywhere before.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made, opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

It is hereby declared that the thesis entitled **“Plasticized Alkali Activated Blast Furnace Slag Paste”** contains literature survey and original research work done by the undersigned candidate, and have been submitted for the partial fulfilment of the continuous assessment of the course of **Master of Construction Engineering with** specialization in **“Structural Repair and Retrofit Engineering”** of **Jadavpur University.**

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

It is also declared that, as required by these rules and conduct, all materials and results that are not original to this work have been fully cited and referenced.

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I feel extremely glad to say that I have got the best knowledge on the matter related to my Thesis work which is submitting in partial fulfilment of the requirement for the Master Degree in Construction Engineering with specialization in **“Structural Repair and Retrofit Engineering”** at *Department of Construction Engineering, Jadavpur University*.

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AAGGBFS	Alkali Activated Ground Granulated Blast Furnace Slag
VMA	Viscosity modified admixture
OPC	Ordinary Portland cement
AAC	Alkali activated composites
XRD	X-ray diffraction
C-S-H	Calcium silicate hydrate
BFS	Blast furnace slag
AASC	Alkali activated slag concrete
AAS	Alkali-activated slag
SEA	Specific energy absorption
DIF	Dynamic increase factor
OPCC	Ordinary Portland cement concrete
SEM	Scanning Electron Microscopy
NMR	Nuclear magnetic resonance
TGA	Thermogravimetric analysis
AM	Alkali modulus
RH	Relative humidity
AAGPS	Alkali-activated ground phosphorous slag
SSD	Surface-saturated-dry
MIP	MercuryIntrusion Porosimetry
w/c	Water cement ratio
EDAX	Energy-dispersive X-ray spectroscopy

Synopsis:

Alkali activated composites are manufactured by activation of base materials, which are rich in alumina and silica in presence metal hydroxide solution etc. like Sodium/Potassium hydroxide. A complex multiphase chemical process which includes a series of stages i.e. Dissolution, Diffusion, Poly-condensation and Hardening, ultimately forming a rigid 3-D alumino-silicate structure [8]. Ground Granulated Blast Furnace Slag (GGBFS), Fly ash, Meta-kaoline, Silica Flume etc. are examples of base materials. Among these base materials, GGBFS has recently gained tremendous attention because of its potential as a source material and its abundant availability from steel plants. Alkali Activated composites have potential to reduce CO_2 emission by about 80% (Davidovits, 1994[9]).It has been observed that alkali activated composites gain high early strength and also proved to be highly durable compared to conventional cement based composites. The chemical composition, morphology and reactivity of alkali activated composites vary significantly with properties of base materials. It is necessary to understand the effects of a various synthesizing parameters and their effects on mechanical properties and microstructure. The alkali activated mix composition is normally controlled by adjusting alkali and silicate content of activating solution. To assess the performance of alkali activated composites using GGBFS , a systematic study on fresh and mechanical properties, pore structure and porosity etc. are essential.

The reactivity and strength development of slag depend on various factors such as chemical composition, glassy phase content, particle size distribution, surface morphology, type of activator and alkali content [18]. The dissolution of the glassy phase is a very important characteristic for hydration of GGBFS. Hydration, Dissolution, Hydrolysis, Ion exchange and Condensation may occur simultaneously. The dissolution process of slag is enhanced with the increase of pH. When alkali concentration increases gradually, the rate of reaction increases and reach an optimum value when no unreacted slag particles present in the paste and produce a high performance composite which are more durable, impermeable and provide better engineering properties but may have a negative effect on workability, which is a real challenge.

The objective of the present investigation is to produce Alkali Activated blast furnace slag composite of reasonably high strength and workability. The effect of different synthesizing parameters on the hardened properties of Alkali Activated GGBFS paste have been investigated. A mixture of sodium hydroxide pallet and sodium silicate solution, has been selected as activator . Set retarding admixture “Master Pozzolith 44r” of BASF Ltd. has also used along with Water reducing admixture, Polycarboxyl based “Master Glenium ACE 30JP” of BASF in presence of VMA “Sika viscocrete 2004 NS” , to maintain desired workability, cohesiveness and setting time.

The presence of internal pore structure have been appreciated by estimating Water absorption, Sorptivity, Apparent porosity, Bulk density, Specific gravity and weight loss. Tests conducted to get compressive strength and micro-structural study have been made to appreciate the overall performance of Alkali Activated GGBFS pastes. It may be noted here that these areas have not received much attention in the past and needs more systematic study.

An attempt has been made to study the overall performance of Admixed Alkali Activated GGBFS composites. Percentage of Na_2O varied from 4% to 10% , Silicate ratio (SiO_2/Na_2O) varied from 0.8 to 1.2 and Water/GGBFS ratio varied from 0.35 to 0.30 by weight. The effect of various synthesizing parameters on Compressive strength, Workability, Water absorption, Sorptivity, Bulk Density and Apparent porosity have been studied along with micro-structural study like SEM .

Apparent porosity, Water absorption, Compressive strength and Water sorptivity of Alkali activated GGBFS composites are measured after 28 days of water curing and then left in air for 48 hrs.. Paste specimens have been also exposed to Sulphuric acid solution and similar tests as discussed above have been performed. Alkali Activated paste specimens have been exposed to different Sulphuric acid concentrations i.e. 2%, 4% and 6%. Alkali and silicate contents are both kept from 8 % to 10% . The Alkali Activated GGBFS pastes are exposed to Sulphuric acid solutions for 7 days, 14 days and 21 days. The test results have been presented in graphical as well as in tabular form, followed by scientific interpretations. Some broad conclusions have been made based on experimental results and areas of future research have been indicated.

1.1 Preamble

Alkali Activated Composites like Geopolymers are materials based on pure alumino-silicate source materials such as fly ash; granulated blast furnace slag obtained from industrial wastes or calcined clays like metakaoline, activated with an alkali metal hydroxide and silicate solution [7]. The expression “geopolymer” was coined by Davidovits in the 1980’s due to their setting mechanism, a polycondensation process under alkaline conditions, similar to organic polymers. Formation of Alkali Activated composites is a complex multiphase exothermic process, involving a series of dissolution-reorientation-solidification reactions analogous to those observed in zeolite synthesis. High alkaline activators are used to induce the silicon and aluminum atoms in the source material to dissolve and form alkali activated gel. The sol gel formation (or polymerization) may be assisted by application of heat, followed by drying. The alkali activated gel binds the loose coarse aggregate, fine aggregate and un-reacted source material to form Alkali Activated composites. The Portland cement free Alkali Activated composites have many advantages like less curing time, earlier development of higher mechanical strength, very little drying shrinkage and very low creep, excellent resistance to sulfate attack, good acid resistance and resistance to high temperature. The strength development in Alkali Activated composites depends on the chemical composition, morphology and reactivity of source materials, chemical composition of activating solution and curing process.

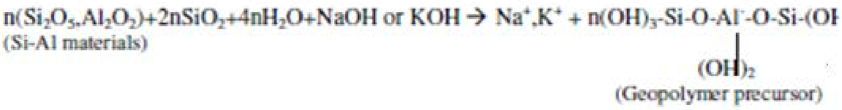
Reports of earlier study with regard to OPC resistance to chemical attacks such as acids and sulphates indicate poor performance and hence render it unsuitable in such adverse conditions. This has been attributed to high CaO content in ordinary portland cements which readily dissolve in acids and also form gypsum and ettringite when exposed to sulphates. In the past few decades, alkali activated composite binders have emerged as one of the possible alternative to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness.

Since Alkali Activated composites relies on alumina-silicate rather than calcium silicate hydrate bonds for structural integrity, they have been reported as being acid resistant.

1.2 Alkali Activated Composite terminology and chemistry

Alkali Activated Composites are members of the family of inorganic polymers. The chemical composition of the Alkali Activated Composites material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline.

The schematic formation Alkali Activated Composites can be shown as described by Equations (1.1) and (1.2).

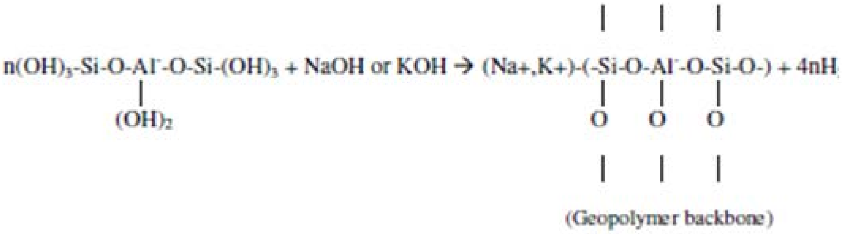


$$n(Si_2O_5,Al_2O_2)+2nSiO_2+4nH_2O+NaOH \text{ or } KOH \rightarrow Na^+,K^+ + n(OH)_3\text{-Si-O-}\underset{(OH)_2}{Al^-}\text{-O-Si-(OH}$$

(Si-Al materials)

(Geopolymer precursor)

(1.1)



$$n(OH)_3\text{-Si-O-}\underset{(OH)_2}{Al^-}\text{-O-Si-}(OH)_3 + NaOH \text{ or } KOH \rightarrow (Na+,K+)\text{-(-}\underset{O}{Si}\text{-O-}\underset{O}{Al^-}\text{-O-}\underset{O}{Si}\text{-O-)} + 4nH$$

(Geopolymer backbone)

(1.2)

The chemical reaction may comprise the following steps :-

- Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- Transportation or orientation or condensation of precursor ions into monomers
- Setting or poly-condensation / 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.

The last term in Equation 2-3 reveals that water is released during the chemical reaction that occurs in the formation of Alkali Activated Composites This water, expelled from the Alkali Activated Composites matrix during the curing and further drying periods, leaves behind discontinuous nano-pores in the matrix, which provide benefits to the performance of Alkali Activated Composites. The water in a geopolymer mixture, therefore, plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement mixture during the hydration process.

A Alkali Activated Composites can take one of the three basic forms: Sialate is an abbreviation for silicon-oxo-aluminate. Polysialates are chain and ring polymers with Si^{4+} and Al^{3+} in IV-fold coordination with oxygen and range from amorphous to semi-crystalline [12].

- Poly (sialate), which has [-Si-O-Al-O-] as the repeating unit.
- Poly (sialate-siloxo), which has [-Si-O-Al-O-Si-O-] as the repeating unit.
- Poly (sialate-disiloxo), which has [-Si-O-Al-O-Si-O-Si-O-] as the repeating unit.

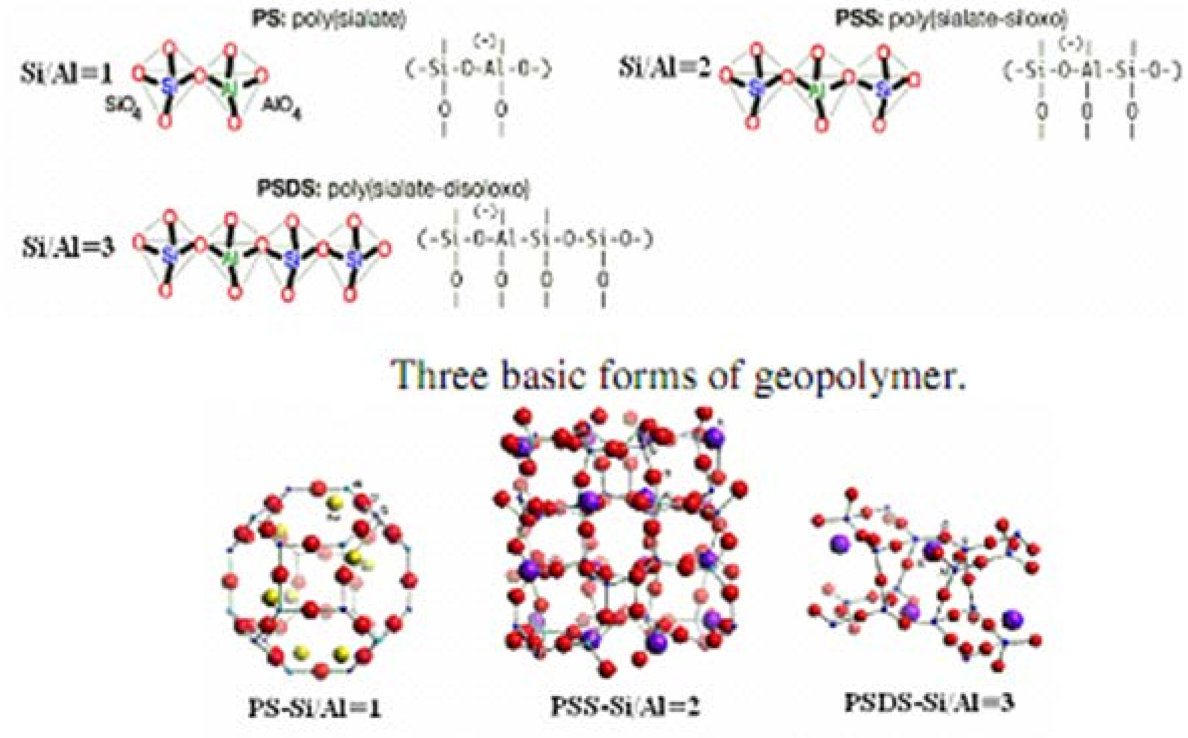


Fig. 1.2.1
Polymeric structures from polymerisation of monomers

1.3. Role of constitutive material in Alkali Activated Composites(AAC)

Source material and Alkaline liquid

Source material

Alkali Activated Composites based on alumino-silicate should be rich in silicon (Si) and aluminium (Al). Several minerals and industrial by-product materials have been investigated in the past. There are three different models for alkali activated cements.

The first type is obtained by the alkali activation of materials comprising primarily of aluminium and silicon with low-calcium contents. In this case more severe conditions (high alkalinity and curing temperatures from 60 to 200 ºC) are required. The main reaction product formed in this case is a three-dimensional alkaline inorganic polymer, an alkaline alumino-silicate gel that can be regarded to be a zeolite precursor.

The second type is obtained by the alkali activation of calcium and silicon rich materials such as ground granulated blast furnace slag. In this case the main reaction product is a calcium silicate hydrate or C-S-H gel similar to the gel obtained during Portland cement hydration.

A third group of materials has recently come to the attention of researchers and may prove to be of particular interest to the construction industry. This group is the result of alkali activating a blend of the previous two i.e. a Ca, Si and Al rich material.

Fly ash is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. Fly ash particles are typically spherical, finer than Portland cement and lime, ranging in diameter from less than 1 μm to no more than 150 μm. The physical and chemical characteristics depend on the combustion methods, coal source and particle shape. The chemical compositions of various fly ashes show a wide range, indicating that there is a wide variation in the coal used in power plants all over the world.

Fly ash that results from burning sub-bituminous coals is referred as ASTM Class C fly ash or high-calcium fly ash, as it typically contains more than 20 percent of CaO. On the other hand, fly ash from the bituminous and anthracite coals is referred as

ASTM Class F fly ash or low-calcium fly ash. It consists of mainly an alumino-silicate glass, and has less than 10 percent of CaO. The colour of fly ash can be dark grey, depending upon the chemical and mineral constituents.

Ground granulated blast furnace slag (GGBFS) is an industrial by-product generated during manufacturing of pig iron and steel and may be defined according to ACI-116R as “non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace”. According to Neville [20], there is about 300 kg of the slag produced together with 1000 kg of the pig iron. Ground granulated blast-furnace slag can be activated with alkalis to obtain a clinker-free binder systems helps saving natural raw materials and decreases the overall energy required to produce a cementitious material as well as reduces the carbon dioxide emissions [18]. The principal constituents of iron and steel slags are oxides of silicon (SiO_2), aluminium (Al_2O_3), calcium (CaO), and magnesium (MgO, which make up 95% of the composition and minor elements includes sulphur compounds, Fe and Mn, as well as trace amounts of several other elements.

The fineness of the BFS is a key factor influencing the reaction, setting, strength development and final microstructure of AAMs. Wang et al. and Puertas have indicated that the optimal fineness range of BFS for the production of AAM is between 400 m^2/kg and 550 m^2/kg. Brough and Atkinson identified that using BFS with an increased fineness promotes the development of higher compressive strengths, which is consistent with the increased reactivity of the material at smaller particle size. However, the setting rate can be strongly affected by the fineness of the BFS. Talling and Brandstetr reported that the use of finely ground BFS beyond 450 m^2/kg gave setting times between 1 to 3 minutes, meaning that the material was impossible to pour.

Alkaline activator

Fly ash, slag and other alumina silicate materials need to be activated using alkalis to form the resulting binding material.The most common alkaline liquid used in polymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

Alkali hydroxides

Chemical compounds composing of an alkali metal cation and the hydroxide anion (OH^-) are called alkali hydroxides. They are the most widely used as activating agents. Sodium and potassium hydroxides are the most commonly used alkali hydroxides in the production of alkali activated binders.

Alkali silicates

Sodium silicate is a very common alkali silicate used as activating agent for alkali activated binder systems. Sodium silicates are available in solid as well as in liquid form. Liquid sodium silicates are commercially termed as waterglass. Solid sodium silicate consists of a chain of polymeric anions composed of corner shared [SiO_4] tetrahedral. Different grades of sodium silicate are generally characterized by their silica modulus (SiO_2-to-Na_2O (or K_2O) ratio), which varies from 1.6 to 3.3. Commonly available waterglass has a silica modulus of 1.60 to 3.85 and contains 36-40% solids. It has been reported that waterglass are the most effective activators for most alkali-activated cementing materials. NaOH is often added to a sodium silicate solution to lower the silicate modulus to a more desired value. This method allows production of waterglass of the optimal modulus and concentration directly.

1.4 Reaction mechanism of Alkali Activation of GGBFS

Alkali hydration of a GGBFS corresponds to a complex process that is composed of several steps, including the initial destruction of the GGBFS and a later poly-condensation of the reaction products. Considering the glassy phase contains high Ca and low Al, Fig. 1.4.1. provides an illustration of the dissolution mechanism of a glass containing both monovalent and divalent network-modifying cations [21]. The primary distinction between the Na+ and Ca2+ sites shown is the much greater extent of “damage” caused to the glass structure by the removal of a divalent cation than a monovalent one.Krizan and Zivanovic [13] analysed the heat release in Alkali-Activated GGBFS, and have noticed that the higher Na_2O and silica modulus (Ms) were related to higher hydration levels. Meanwhile, the process begins with a destruction of the slag bonds Ca–O, Mg–O, Si– O–Si, Al–O–Al and Al–O–Si, and then a Si–Al layer formed all over the surface of slag grains and, finally, the formation of the hydration products.

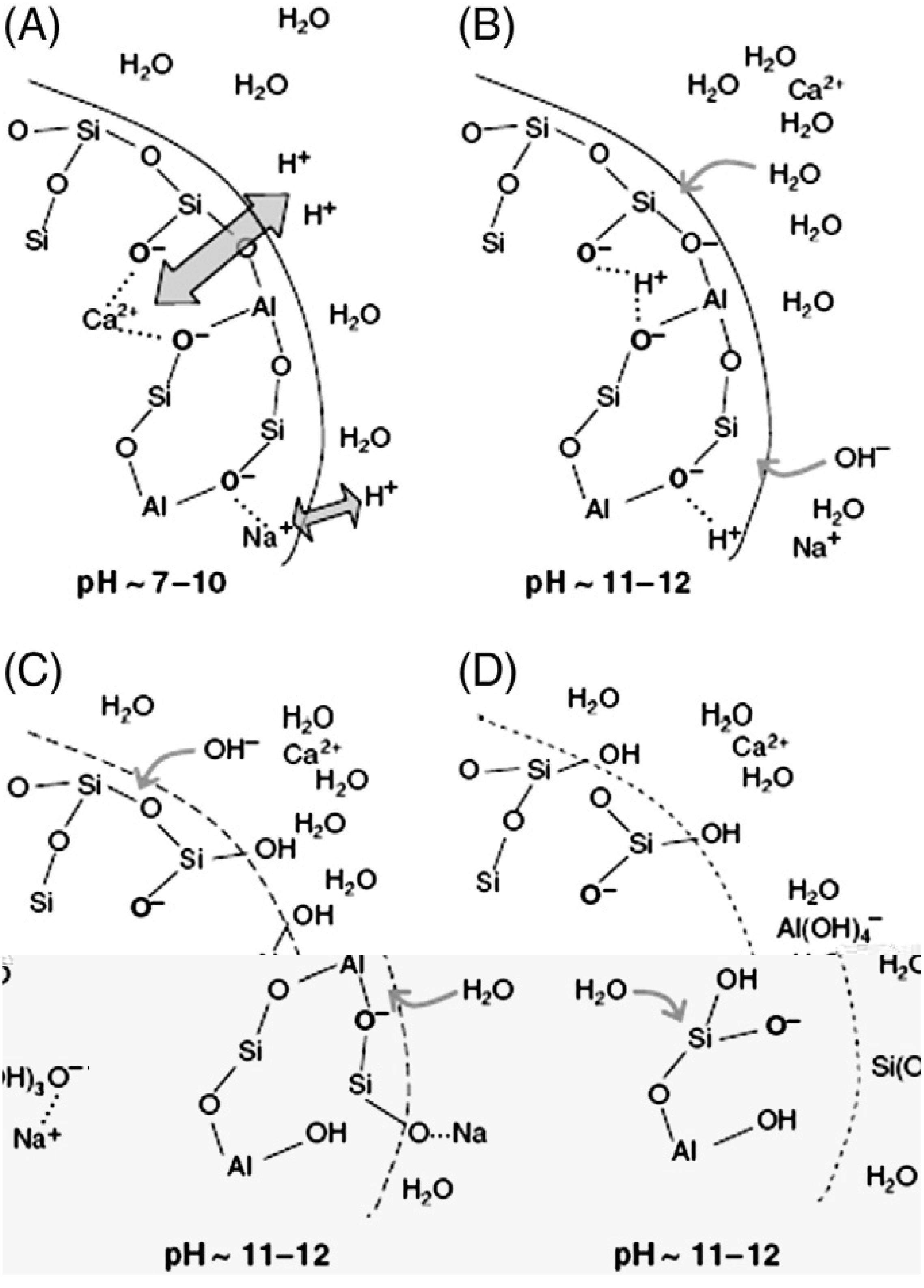


Fig. 1.4.1. Dissolution mechanism of an alumina-silicate glass during the early stage of reaction: (A) exchange of H+ for Ca2+ and Na+, (B) hydrolysis of Al–O–Si bonds, (C) breakdown of the depolymerized glass network, and (D) release of Si and Al. Charged framework oxygen sites are marked in bold; note the charge transfer reaction occurring between panels (B) and (C), and proton transfer throughout. All framework Si and Al sites are tetrahedrally coordinated to oxygen, but additional bonds are not shown for clarity [21].

1.5. Applications of Alkali Activated Binder Systems

Alkali Activated binder systems have diverse applications. The commercial products developed using Alkali Activated binder systems include structural concrete, masonry blocks, concrete pavements, concrete pipes, utility poles and concrete sinks and trenches. It is also used in the development of autoclaved aerated concrete, refractory concrete and oil-well cements. Most of the commercial applications of this system have taken place in the former Soviet Union, China, and some Scandinavian countries.

Alkali Activated concretes also have been used as repair materials due to their superior early age strengths (in most cases, depending on the activator and source material chemistry) and better bonding with the substrate material. Geopolymers are ideal for high temperature applications as they remain structurally stable at temperatures up to800°C.

One of the potential fields of application of geopolymeric materials is in toxic waste management because geopolymers behave similar to zeolitic materials that have been known for their ability to absorb the toxic chemical wastes.

In Australia, the geopolymer technology has been used to develop sewer pipeline products, railway sleepers, building products including fire and chemically resistant wall panels, masonry units, protective coatings and repairs materials, shotcrete and high performance fibre reinforced laminates (Gourley, 2003; Gourley & Johnson, 2005).

Si / Al	Application
1	Bricks, ceramics, fire protection
2	Low CO_2 cements, concrete, radioactive and toxic waste encapsulation
3	Heat resistance composites, foundry equipment, fiber glass composites
>3	Sealants for industry
20>Si / Al<35	Fire resistant and heat resistant fiber composites

Table 1.1: Applications of alkali alumino-silicates

1.6 Objective of present research

The objective of the present investigation is to produce Alkali activated blast furnace slag composite of reasonably high strength and workability. The effect of different synthesizing parameters on the hardened properties of alkali activated GGBFS paste have been investigated. A mixture of sodium hydroxide pallet and sodium silicate solution, has been selected as activator . Set retarding admixture “Master Pozzolith 44r” of BASF Ltd. has also used along with Water reducing admixture, Polycarboxyl based “Master Glenium ACE 30JP” of BASF in presence of VMA “Sika viscocrete 2004 NS” , to maintain desired workability, cohesiveness and setting time.

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Apparent porosity, Water absorption, Compressive strength and Water sorptivity of Alkali activated GGBFS composites are measured after 28 days of water curing and then left in air for 48 hrs.. Paste specimens have been also exposed to Sulphuric acid solution and similar tests as discussed above have been performed. Alkali Activated paste specimens have been exposed to different Sulphuric acid concentrations i.e. 2%, 4% and 6%. Alkali and silicate contents are both kept from 8 % to 10% . The Alkali Activated GGBFS pastes are exposed to Sulphuric acid solutions for 7 days, 14 days and 21 days. The test results have been presented in graphical as well as in tabular form, followed by scientific interpretations. Some broad conclusions have been made based on experimental results and areas of future research have been indicated.

2.1 Preamble

Critical review of Alkali Activated Blast Furnace Slag composite indicating performance of fresh paste and engineering properties of hardened product. Curing condition, effect of different alkali activators and hydration chemistry have been indicated. A summary of review done and scope of the present research work have been also included.

2.2 Alkali Activated Composites

2.2.1 Gao Yuan, Xu Jinyu, Bai Erlei, Luo Xin, Zhu Jingsai, Nie Liangxue on "Static and dynamic mechanical properties of high early strength alkali activated slag concrete"(2015)

Gao Yuan et al. studied static and dynamic mechanical properties of high early strength alkali activated slag concrete(AASC). The compressive and flexural strength with 3 h of water curing reached 39.2MPa and 3.26MPa, respectively.

The dynamic increase factor(DIF), max strain, peak toughness and specific energy absorption(SEA) increase with average strain rate in AASC. As compared to ordinary Portland cement concrete(OPCC), AASC has lower DIF, higher deformability and better impact toughness.

2.2.2 N.K. Lee, H.K. Lee on "Reactivity and reaction products of alkali-activated, fly ash/slag paste"(2015)

Lee et al. studied the microstructure, reaction products, and reactivity of alkali-activated, fly ash/slag binders synthesized at various mixture ratios of two raw materials were examined using various experimental techniques (NMR, ICP-OES, EDS, FT-IR and TGA) to systematically investigate the complex reaction mechanism of the binders and was also intended to help assess durability of the binders.

The experiment results found that the amount of added slag primarily affected the amount of reaction product and its silicate structure, and as the amount of added slag increased, the amount of C-S-H gel increased and the amount of aluminosilicate gel decreased.

2.2.3 J.G. Jang, N.K. Lee, H.K. Lee on "Fresh and hardened properties of alkali-activated fly ash/slag pastes with superplasticizers"(2014)

J.G.Jang et al. studied fresh and hardened properties of alkali-activated fly ash/slag pastes with superplasticizers under room temperature curing conditions. The binders were prepared by dry mixing of slag and fly ash with 5 different slag-to-binder ratios, i.e., slag / binder = 0, 0.3, 0.5, 0.7,1, NaOH and sodium silicate solution used as an alkali activator. The polycarboxylate-based and naphthalene-based superplasticizers were added to the mixes at the levels of 0%, 1%, 2%, 3%, and 4% by the mass of binder.

The experiment results showed that the higher contents of slag increased the compressive strength of alkali-activated fly ash/slag pastes, but caused rapid setting and crack due to autogeneous shrinkage in the cases of 70% and 100% of slag to binder ratios. The polycarboxylate-based superplasticizer showed retarding effect on alkali-activated fly ash/ slag pastes with negligible effect on the heat of hydration, and improved the workability more significantly than naphthalene-based superplasticizer. The samples were also studied by SEM/EDS and observed that a higher content of slag led to the formation of denser matrix of hydration products but the formation of hydration products was not noticeably affected by the addition of superplasticizers.

2.2.4 Alireza Kashani, John L. Provis, Greg G. Qiao, Jannie S.J. van Deventer on "The interrelationship between surface chemistry and rheology in alkali activated slag paste"(2014)

Alireza Kashani et al. studied the effect of activator type and dosage on rheology by monitoring changes in pH, particle surface charge (zeta potential), and heat evolution in the early stages of the reaction process and Sodium and potassium hydroxide silicate solutions, at two different M_2O (M: Na, K) dosages, are used as activators where Alkali hydroxide activators cause a significant increase in the yield stress of an activated slag paste, especially at higher dosages as reactions take place rapidly, while within the same timeframe, the yield stress of the silicate activated slag remains unchanged.

The experiment results imply a direct relationship between a higher reaction rate with the formation of solid products (causing both spatial blockage effects and consumption of free water), and a rapid yield stress increase and a direct relationship is observed between the dosage of the activators and zeta potential. A zeta potential further from neutrality generally reduces yield stress by increasing the magnitude of double layer repulsive forces, with the exception of a higher dosage of silicate activator, which shows an indication of some attractive double layer forces.

2.2.5 F. Puertas, C. Varga, M.M. Alonso on "Rheology of alkali-activated slag pastes. Effect of the nature and concentration of the activating solution"(2014)

Puertas et al. studied the effect of factors such as the nature and concentration of the alkaline activator on the rheological behaviour of alkali-activated slag (AAS) pastes, with a comparison between the rheological parameters and fluidity of these pastes to the same parameters in OPC and also showed the paste rheology was affected by the nature of the alkaline activator (NaOH, 50/50 wt% NaOH/Na_2CO_3 or waterglass – Wg), its concentration (3–5% Na_2CO_3 of slag weight) and, in the waterglass solution, the SiO_2/Na_2O ratio.

The experiment results found that rise in alkaline activator concentration from 3% to 5% Na_2O raised the shear stress in AAS systems and a relationship was identified between the SiO_2/Na_2O ratio and Na_2O concentration in primary C–S–H gel formation: the higher the Na_2O concentration, the lower was the SiO_2/Na_2O ratio required in this gel formation.

2.2.6 Serdar Aydın, Bulent Baradan on "Effect of activator type and content on properties of alkali-activated slag mortars"(2014)

Aydin et al. studied the effect of activators sodium silicate and sodium hydroxide on alkali activated slag mortars and objective was to determine the SiO_2/Na_2O ratios (MS) and Na_2O contents of the solutions on the development of workability, setting times, mechanical properties, drying shrinkage, water absorption characteristics and microstructure of alkali activated slag cement binders.

The results showed that portland cement free high performance composite with compressive strength values about 100 MPa can easily be achieved by activation of slag without heat curing and M_S and Na_2O contents of activator solution had great importance on the properties of AAS. Sodium silicate activated AAS mortars presented higher compressive strength, lower water absorption, higher workability, lower porosity and a wide range of setting times compared to NaOH activated AAS mortars and Portland cement mortar when activated by optimum Ms ratio.

2.2.7 Hailong Ye, Christopher Cartwright, Farshad Rajabipour, and Aleksandra Radlińska on "Effect of Drying Rate on Shrinkage of Alkali-Activated Slag Cements"(2014)

In this paper studied the influence of drying rate on drying shrinkage behaviour of AAS mortars to better understand the mechanisms responsible for its large shrinkage deformation. A series of four AAS mortar mixtures with varying activator composition, as well as a reference Portland cement mortar, was cast and dried at different relative humidities, that is, 30, 50, 70, and 85% RH.

The results showed that shrinkage of AAS varies largely depending on the drying rate, that is, ambient RH though the drying mass loss increases with reducing the RH, the magnitude of shrinkage is the largest for samples stored at 50 and 70% RH, depending on the mixture type. It is concluded that the drying rate has a much more significant influence on AAS than on ordinary Portland cement (OPC), which implies a more complicated shrinkage mechanism for AAS samples stored at various relative humidities.

2.2.8 D.V.S.P. Rajesh, A. Narender Reddy, U. Venkata Tilak, M. Raghavendra on "Performance of alkali activated slag with various alkali activators"(2013)

Rajesh et al. studied the performance of alkali activated slag concrete with sodium silicate, sodium hydroxide, sodium carbonate as activator were used at 4% Na_2O(by weight of slag) and 4% of hydrated lime by total weight of solid binder content if used as retarder. The fresh concrete properties studied were setting time and workability and the Engineering properties studied are compressive strength was measured in 1,7,28 days, split tensile strength was measured in 7, 28 days and flexure, punching shear strength was compared in 12 days only.

The results showed that Sodium silicate activated slag concrete sets rapidly with the higher Na_2O dosage resulting in shorter setting time and the setting time can be prolonged by adding hydrated lime to mix, which increases the final setting time more when compared to initial setting time. Out of all these activators NaOH is best; Na_2CO_3 was the second; Na_2SiO_3 was the third in terms of flexural and punching shear test. In compressive test the strength growth rate in early age is high when compared to traditional concrete and in flexure test the cement mix gives the higher load carrying capacity but less ductility whereas Na_2CO_3 mix shows lower load carrying capacity but very high ductility. In punching shear test, among all the AAS concrete mixes, NaOH gives higher punching strength when compared to the other two AAS mixes. Na_2SiO_3 gives the very less strength compare to all mixes.

2.2.9 N. Jambunathan, J.G. Sanjayan, Z. Pan[a], G. Li, Y. Liu, A.H. Korayem, W.H. Duan, F. Collins on "The role of alumina on performance of alkali-activated slag paste exposed to 50 °C"(2013)

In this paper studied the strength and microstructural evolution of two alkali-activated slags, one was ground-granulated blast furnace slag (containing 13% (wt.) alumina) and other phosphorous slag (containing 3% (wt.) alumina) exposed to 50 °C used a combination of sodium hydroxide and sodium silicate solution at different ratios. The microstructure of the resultant slag pastes was assessed by X-ray diffraction, differential thermogravimetric analysis, and scanning electron microscopy.

The results showed that the presence of hexagonal hydrates: CAH_{10} and C_4AH_{13} in all alkali-activated ground-granulated blast furnace slag pastes (AAGBS) and these hydrates were not observed in pastes formed by alkali-activated ground phosphorous slag (AAGPS). Upon exposure to 50 °C, the aforementioned hydration products of AAGBS pastes convert to C_3AH_6, leading to a rapid deterioration in the strength of the paste. In contrast, no strength loss was detected in AAGPS pastes following exposure to 50 °C.

2.2.10 Mohd. Nadeem Qureshi and Somnath Ghosh on "Effect of Curing Conditions on the Compressive Strength and Microstructure of Alkali-activated GGBS paste"(2013)

In this paper presented the effect of curing method on the strength development of alkali- activated blast furnace slag paste and studied alkali activation was done using a combination of potassium hydroxide and sodium silicate. The test parameters include the curing methods (water curing at 27^0C, heat curing at 500C and controlled curing with relative humidity 50%, 70% and 90 % at 270 C), alkali content with 6.41 %, 8.41 %, 10.41% and 12.41 % of the mass of GGBS.

The results showed that the increase in compressive strength with the increase in age of water curing and controlled curing specimens and a comparison of hot cured specimens, the increase in compressive strength with age was less. Heat cured specimens showed adverse effect on compressive strength and to create internal micro cracking as well as surface cracks. The higher compressive strengths were obtained from water cured specimens.

2.2.11 M. Ben Haha, B. Lothenbach, G. Le Saout, F. Winnefeld on "Influence of slag chemistry on the hydration of alkali-activated blast-furnace slag — Part II: Effect of Al_2O_3"(2012)

In this paper studied the hydration and microstructural evolution of three alkali activated slags (AAS) with Al_2O_3 contents between 7 % and 17% wt. The slags were hydrated in the presence of two different alkaline activators, NaOH and $Na_2SiO_3 \cdot 5H_2O$ and the formation of C(\A)–S–H and hydrotalcite was observed in all samples by X-ray diffraction, thermal analysis and scanning electron microscopy.

The results showed that higher Al_2O_3 content of the slag decreased the Mg/Al ratio of hydrotalcite, increased the Al incorporation in the C(A)-S-H and led to the formation of strätlingite. Increasing Al_2O_3 content of the slag slowed down the early hydration and a lower compressive strength during the first days was observed and at 28 days and longer, no significant effects of slag Al_2O_3 content on the degree of hydration, the volume of the hydrates, the coarse porosity or on the compressive strengths were observed.

2.2.12 Chao Li, Henghu Sun, Longtu Li on “The comparison between alkali-activated slag (Si+Ca) and metakaolin (Si+Al) cements”(2010)

In this paper studied two main models of alkali-activated cements, one is the case of the activation of slag (Si+Ca) and the other is activation of metakaolin (Si+Al) and discussed the comparison between alkali-activated slag (Si+Ca) and metakaolin (Si+Al) cements, including the general properties of slag and metakaolin, hydration products reaction mechanisms, and the role of Ca and Al.

The results showed that the Alkali activation of GGBFS is a model of (Si + Ca) system, and geopolymer is a kind of (Si + Al) cement with metakaolin and fly ash as main material. The chemical component of GGBFS consists mainly of the $CaO–SiO_2–MgO–Al_2O_3$ system, and is described as a mixture of phases with compositions resembling gehlenite ($2CaO\cdot Al_2O_3\cdot SiO_2$) and akermanite ($2CaO\cdot MgO\cdot 2SiO_2$), as well as a depolymerized calcium aluminosilicate glass. The key glass network forming cations are Si^{4+} and Al^{3+}, and the divalent Ca^{2+} and Mg^{2+} act as network modifiers along with any alkalis present while in metakaolin, the two major components are SiO_2 and Al_2O_3. Metakaolin is a thermally activated aluminosilicate material with high pozzolanic activity comparable to or exceeded the activity of fume silica. And it is generated by calcination of kaolinitic clay at temperature of between 650°C and 800°C depending on the purity and crystallinity of the precursor clays.

2.2.13 Jae Eun Oh, Paulo J.M. Monteiro, Ssang Sun Jun, Sejin Choi, Simon M. Clark on “The evolution of strength and crystalline phases for alkali-activated ground blast furnace slag and fly ash-based geopolymers”(2010)

In this paper studied the increase in strength and evolution of crystalline phases in inorganic polymer cement, made by the alkali activation of slag, Class C and Class F fly ashes, followed using compressive strength test and synchrotron X-ray diffraction.

2.2.14 M. Palacios, Y.F. Houst, P. Bowen, F. Puertas on “Adsorption of superplasticizer admixtures on alkali-activated slag pastes”(2009)

In this paper studied the adsorption of different superplasticizer admixtures (naphthalene based, melamine-based and a vinyl copolymer) on the slag particles in AAS pastes using alkaline solutions with different pH values and the effect of the superplasticizers on the yield stress and plastic viscosity of the AAS and OPC pastes have been also evaluated.

The results showed that the adsorption of the superplasticizers on AAS pastes is independent of the pH of the alkaline solutions used and lower than on OPC pastes. The effect of the admixtures on the rheological parameters depends directly on the type and dosage of the superplasticizer as well as of the binder used and, in the case of the AAS, on the pH of the alkaline activator solution. In 11.7-pH NaOH-AAS pastes the dosages of the superplasticizers required to attain similar reduction in the yield stress are ten-fold lower than for Portland cement. In 13.6-pH NaOH-AAS pastes, the only admixture observed to affect the rheological parameters is the naphthalene-based admixture due to its higher chemical stability in such extremely alkaline media.

2.2.15 M. Palacios, F. Puertas on “Effect of superplasticizer and shrinkage-reducing admixtures on alkali-activated slag pastes and mortars”(2005)

In this paper studied the effect of mechanical and rheological properties and setting times of alkali-activated slag pastes and mortars using several superplasticizers (polycarboxylates, vinyl copolymers, melamine and naphthalene-based) and shrinkage reducing (polypropylenglycol derivatives) admixtures. Two activator solutions, waterglass and NaOH, were used, along with two concentrations—4% and 5% of Na2O by mass of slag. The results showed that all admixtures, with the exception of the naphthalene-based product, lost their fluidifying properties in mortars activated with NaOH as a result of the changes in their chemical structures in high alkaline media.

2.2.16 J.J. Chang on "A study on the setting characteristics of sodium silicate-activated slag pastes"(2003)

Chang studied the factors such as the pH value of the activator, the alkali modulus (AM) and the alkali activator dosage, influences the setting time of alkali-activated slag (AAS) paste for a sodium silicate-based activator where liquid/slag ratio was kept constant.

The results showed that the pH value and the AM have a strong relationship but no distinct relationship with the setting time. The activator dosage, which is defined as the sum of the SiO_2 and Na_2O concentrations, shows a significant trend with the setting time and was also found that the influence of SiO_2 on the setting time is more apparent than that of Na_2O. Increasing amounts of SiO_2 decrease the pH value of the activator and increasing amounts of Na_2O increase the pH value of the activator. Phosphoric acid, used as a retarder, was found to have a strong retarding effect.

2.2.17 Jose Ivan Escalante-Garcia, Victor M. Palacios-Villanueva, Alexander V. Gorokhovsky, Guillermo Mendoza-Sua´rez, and Antonio F. Fuentes on "Characteristics of a NaOH Activated Blast Furnace Slag Blended with a Fine Particle Silica Waste"(2002)

In this paper studied the mortars of blast furnace slag blended with a geothermal silica waste at various replacement levels of 0%, 5%, 10%, 15%, and 20% were cured for up to 90 days and the binder was activated by 6 wt% Na_2O equivalent of sodium hydroxide. Lime was added as an activating agent and also to promote pozzolanic reaction with the silica.

The results showed that the presence of the silica waste increased the reactivity of the cementitious materials, as measured by means of non-evaporable water and the compressive strength was increased in the presence of the silica, except at the highest replacement level of 20%, the optimum silica replacement was that of 5%–10%. The microstructures of blended slag showed less porosity than those of neat slag mortars. The lime was completely consumed after 90 days of hydration.

2.2.18 A.R. Brough, A. Atkinson on “Sodium silicate-based, alkali-activated slag mortars Part I. Strength, hydration and microstructure”(2002)

In this paper studied strength, hydration and microstructure of sodium silicate-based, alkali-activated slag mortars. Hydration was investigated by scanning electron microscopy (SEM; with quantitative image analysis) and Si magic angle spinning nuclear magnetic resonance (MAS NMR).

The results showed that at early age, a uniform gel filled the initially water filled space, and gradually densified as reaction proceeded. Microanalysis of outer product (OP) showed an Al-substituted C–S–H gel phase of widely variable (0.5–1.0) Ca/Si ratio and NMR showed long-chain substituted C–S–H with Al/Si ratio rising to 0.19 at 1 year, and also cross-linked material, consistent with a Ca- or Al-modified silica gel. Inner product (IP) regions around slag grains probably also contained hydrotalcite. Activation with KOH gave more rapid reaction of slag than for silicate activation, a less homogeneous microstructure, and lower strengths. The hydrates contained a substituted C–S–H gel of low Ca/Si ratio probably mixed with hydrotalcite, and occasional higher Al regions in the OP regions.

2.2.19 S. Song, D. Sohn, H. M. Jennings, T. O. Mason on “Hydration of alkali-activated ground granulated blast furnace slag”(2000)

In this paper the hydration of ground granulated blast furnace slag (GGBFS) at 25^{o}C in controlled p^{H} environments was investigated during 28 days of hydration. GGBFS was activated by NaOH, and it was found that the rate of reaction depends on the p^{H} of the starting solution and the effect of the p^{H} of the aqueous solution on the composition, microstructure and properties of alkali-activated GGBFS pastes were also discussed.

The results showed that the addition of NaOH as an activator buffers the p^{H} of pore fluids and the rate of hydration depends on the p^{H} of the solutions: the higher the concentration of NaOH, the faster the hydration of GGBFS.

NaOH-activated GGBFS pastes have more capillary porosity compared to conventional cement pastes and the concentration of NaOH in the initial mixing solution significantly affected the formation of the main hydration product, C-S-H.

The microstructure of GGBFS pastes may vary according to the p^{H} of the pore solution and the Ca/Si ratio of the C-S-H.

The pH of the mixing solution may also affect the nature of C-S-H and its Ca/Si ratio by controlling the solubility of each component and the low concentration of Ca and high concentration of Si are thermodynamically favored at higher pH and it allows the formation of hydration products of low Ca/Si ratio.

2.2.20 Sujin Song, Hamlin M. Jennings on "Pore solution chemistry of alkali-activated ground granulated blast-furnace slag"(1999)

In this paper studied the chemical composition and pH of the pore solution extracted from six different ground granulated blast-furnace slag (GGBFS) pastes and the concentrations of Si, Ca, Al, and Mg are functions of the pH of the aqueous phase, with high pH associated with the higher concentrations of Si and Al and the lower concentrations of Ca and Mg. When GGBFS is mixed with an aqueous phase with pH higher than 11.5, the reaction is activated or accelerated.

The results showed that the main hydration product was identified as C-S-H, and hydrotalcite, at later stages of hydration, was observed in the pastes with an aqueous phase of a high pH and the effect of pore solution on the alkali activation of GGBFS is discussed with reference to the hydration products.

2.3 Summery on Literature review

The following aspects were appreciated

- Higher concentration of sodium hydroxide solution result higher strength of Alkali Activated concrete.
- Water plays an important role during dissolution, poly-condensation & hardening stages of geo-polymerisation. Reduction of water content improved Compressive strength.
- The fly ash to activator ratio appeared to be the most critical parameter with regards to general strength and fire resistance of the Alkali activated paste.
- Geopolymer mortar specimens manufactured by activation with higher alkali content (%Na_2O) resulted in lower Water absorption, Apparent porosity and Water sorptivity.

- The addition of NaOH as an activator buffers the pH of pore fluids and the rate of hydration depends on the pH of the solutions: the higher the concentration of NaOH, the faster the hydration of GGBFS.
- The NaOH-activated GGBFS pastes have more capillary porosity compared to conventional cement pastes and concentration of NaOH in the initial mixing solution significantly affected the formation of the main hydration product, C-S-H.
- Static mechanic properties: AASC prepared by conventional method can achieve a high early strength at 3 h and this kind of materials has great potential for emergency repair. But the using of water curing is still an obstacle of wide application.
- The dynamical compressive strength in AASC increases with strain rate, but the increase rate is less in AASC than OPCC. The ultimate strain in AASC also increases with strain rate.
- AASC shows a higher deformability than OPCC. The difference between AASC and OPCC may be due to the curing time. The insufficient hydration makes AASC possess a special internal structure which is different from OPCC or AASC cured for a long period.
- The total reactivity of the alkali-activated, fly ash/slag (AFS) paste calculated by an NMR peak analysis was much higher when mixed with the liquid activator compared to the powder activator. The reactivity of the liquid activator was slightly higher than that of the powder activator.
- The polycarboxylate-based superplasticizer showed retarding effect on alkali-activated fly ash/slag pastes with negligible effects on the heat of hydration, and improved the workability more significantly than the naphthalene-based superplasticizer.
- The polycarboxylate-based superplasticizer content beyond 2 wt% positively affected the development of compressive strength before 7 days, whereas it could have adverse effects after this point.
- Alkali hydroxide activators cause a significant increase in the yield stress of an activated slag paste, especially at higher dosages as reactions take place in the fresh paste.
- Setting time and compressive strength were significantly affected by the mixing ratio of slag. Higher contents of slag increased the compressive strength of alkali-

activated fly ash/slag pastes, but caused rapid setting and crack due to autogenous shrinkage in the cases of 70% and 100% of slag to binder ratios.

- The rate of the reaction, as measured by heat evolution, shows a correlation with the time at which the yield stress increases, and therefore the rapid yield stress increase observed with hydroxide activators can be related to the consumption of water and formation of gel reaction products which introduce new inter-particle forces.
- Silicate activated slag shows limited reaction at early age during the induction period, and hence no yield stress increase during this time. Addition of sodium silicate gives a lower yield stress than non-activated slag due to the plasticizing and deflocculating effects of the silicate anions, which adsorb on the particle surfaces, increase the magnitude of repulsive double layer electric forces, and hence reduce the yield stress.
- All activated slag specimens tested show shear thinning and thixotropic behavior. This means that inter-particle forces can be easily broken under the application of higher shear stresses at early age, and constant high-shear mixing of the paste could lower the viscosity for better workability before placement.
- The GGBFS and MK are both very good pozzolanic materials to produce geopolymers or as additives in OPC.
- The Shrinkage Reducing Admixture reduced the shrinkage by up to 85 and 50% when the alkali-activated slag mortar specimens were cured at relative humidities of 99 and 50%, respectively.

2.4. Scope of present research

The scope of the present investigation is to produce Alkali activated blast furnace slag composite of reasonably high strength and workability. The effect of different synthesizing parameters on the hardened properties of alkali activated GGBFS paste have been investigated. A mixture of sodium hydroxide pallet and sodium silicate solution, has been selected as activator . Set retarding admixture “Master Pozzolith 44r” of BASF Ltd. has also used along with Water reducing admixture, Polycarboxyl based “Master Glenium ACE 30JP” of BASF in presence of VMA “Sika viscocrete 2004 NS” , to maintain desired workability, cohesiveness and setting time.

The presence of internal pore structure have been appreciated by estimating Water absorption, Sorptivity, Apparent porosity, Bulk density, Specific gravity and weight loss. Tests conducted to get compressive strength and micro-structural study have been made to appreciate the overall performance of Alkali Activated GGBFS pastes. It may be noted here that these areas have not received much attention in the past and needs more systematic study.

An attempt has been made to study the overall performance of Admixed Alkali Activated GGBFS composites. Percentage of Na_2O varied from 4% to 10% , Silicate ratio (SiO_2/Na_2O) varied from 0.8 to 1.2 and Water/GGBFS ratio varied from 0.35 to 0.30 by weight. The effect of various synthesizing parameters on Compressive strength, Workability, Water absorption, Sorptivity, Bulk Density and Apparent porosity have been studied along with micro-structural study like SEM .

Apparent porosity, Water absorption, Compressive strength and Water sorptivity of Alkali activated GGBFS composites are measured after 28 days of water curing and then left in air for 48 hrs.. Paste specimens have been also exposed to Sulphuric acid solution and similar tests as discussed above have been performed. Alkali Activated paste specimens have been exposed to different Sulphuric acid concentrations i.e. 2%, 4% and 6%. Alkali and silicate contents are both kept from 8 % to 10% . The Alkali Activated GGBFS pastes are exposed to Sulphuric acid solutions for 7 days, 14 days and 21 days. The test results have been presented in graphical as well as in tabular form, followed by scientific interpretations. Some broad conclusions have been made based on experimental results and areas of future research have been indicated.

Preamble

An experimental investigation have been conducted to understand engineering properties of GGBFS based Alkali Activated composites and to appreciate microstructure also. The laboratory tests have been conducted as per relevant Indian standard codes and also ASTM standard. The microstructure have been studied using Scanning Electron microscopy (SEM). The details of test procedures, manufacturing process and specimen cast and tested have been discussed in following sections.

3.1 Manufacturing process of Alkali Activated Composites(AAC) mix

Alkali Activated Composites prepared by mixing GGBFS with alkali activator solution is called alkali activated paste. The GGBFS used in this investigation is obtained from Durgapur Steel Plant. The slag was ground and then sieved so that 100% of particles passed a 45 micron sieve.

The alkaline activator liquid is a combination of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) pellets. Laboratory grade sodium hydroxide in pellets from (Na_2O = 77.5 %, H_2O = 22.5 %) were supplied by Merck India Ltd. with 97% purity. Sodium silicate solution (Na_2O = 8 %, SiO_2 = 26.5%, H_2O = 65.5 %) with a modulus of sodium silicate of ~3.3 and a bulk density of 1410 Kg/m^3 is supplied by Loba Chemie Ltd., India. These are used to adjust the desired composition of alkali activated slag (AAS) paste. The activator solution is prepared at least one day prior to its use.

The mixture is usually homogenous slurry which is white in colour. In present research, for manufacturing of Alkali Activated mixes, following range of different constituents will be selected.

Detail of mixes

- GGBFS : 1000 gm
- Alkali content (%Na_2O) : varies from 4% to 10% by weight of GGBFS
- Silicate ratio (SiO_2 / Na_2O) : varies from 0.8 to 1.2
- Retarding admixture "Master pozzolith 44r" : 1.3% by weight of GGBFS

- Water to GGBFS ratio : varies from 0.35 to 0.30
- Water reducing admixture of BASF “Master Glenium ACE 30JP” : 1.3% by weight of GGBFS
- Viscosity modified admixture(VMA) “Sika viscocrete 2004 NS” : 1.3% by weight of GGBFS

Figure-3.1 : Preparation of GGBFS Paste in Mortar Mixer

Following manufacturing process will be adopted for preparing Alkali Activated composite specimens.

- Mix sodium silicate solution, sodium hydroxide pellets and water according to mix proportion, to make alkaline activator, at least one day prior to its use in manufacturing alkali activated composite.
- Mortar mixer with rotating blades is used for preparing Alkali Activated GGBFS paste.
- Mix GGBFS, alkaline activator, retarding admixture and water reducing admixture with VMA in the Mortar mixer for about four to five minutes to make homogeneous paste.
- Transfer alkali activated mix to moulds of size 50 x 50 x 50 mm.
- Vibrate fresh alkali activated mix in the moulds on vibration table for 2-3minutes to remove entrapped air in the mix.
- Rest period of 60 minutes is given to fresh specimens prior to placing them in the water for water curing for 28 days.
- Removed specimen from moulds at room temperature.

3.2 Testing and characterization of Alkali Activated Composites:

The main purpose of testing of Alkali Activated composites is to investigate the engineering properties of GGBFS based alkali activated composites and to characterize microstructure of alkali activated specimens, synthesized at different test conditions. The laboratory tests will be conducted as per relevant Indian standard codes and in some special tests, ASTM standard may be followed. The microstructure characterization of alkali activated will also be carried out using XRD and SEM. The details of various test procedure use in the present research are described in the following sections.

3.2.1 Workability measurements

The workability is assessed using a mini flow table test as per ASTM C1437-07 [2], with one modification: the table was raised and dropped 15 times in about 15s. The mini flow table apparatus was used as per ASTM C 230/C 230 M [4]. The workability of the mix was determined by measuring the diameter of paste flow on a flow table in two perpendicular directions after 15 drops in 15s, and the average value was considered as a flow diameter [24]. The percentage increase in the flow diameter with respect to the initial diameter of the mold was considered as the flow value. All the tests were repeated three times, and the average flow was considered. Depending on flow diameter, workability of alkali activated mix may be classified as stiff, moderate and high.

Figure 3.2: Mini flow table as per ASTM C1437-07

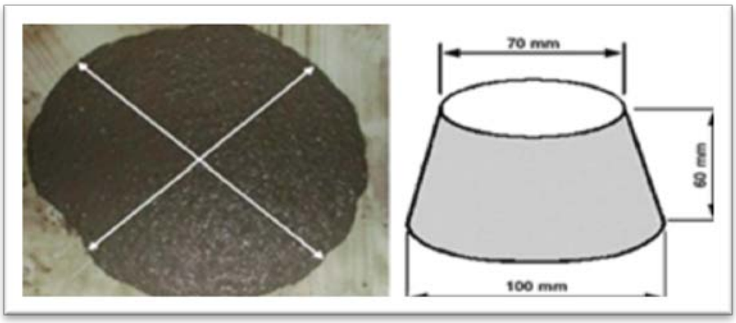


Figure 3.3: Measurement of Workability using mini slump cone

3.2.2 Bulk density and Apparent porosity

The bulk density and apparent porosity for alkali activated specimen is determined for 28 days old specimens using following relation according to Archimedes principle with water as immersion medium.

Bulk density (Kg/m^3) = [D / (W - S)] x 1000
Apparent Porosity (%) = [(W - D) / (W - S)] x 100

where D is the weight of oven-dried sample in kg, W is the saturated weight of sample in kg and S is the weight of water saturated sample suspended in water in kg.

3.2.3 Compressive strength

The direct Compressive strength of hardened alkali activated specimens will be obtained at the age of 7 and 28 days, using 2000kN capacity digital compressive testing machine. At 7 days age, three identical samples were tested in accordance with ASTM C-109 -02 [1] and the mean values of compressive strength are reported in relevant tables and graphs.

Figure-3.4: Compression testing machine

3.2.4 Water absorption

To determine the Water absorption, three cube specimens from each series were oven dried at a temperature of 85^{o}C for 24h and its weight was determined (initial weight). The specimens were then immersed in water for 24h and its saturated surface dry weight was recorded(final weight). Water absorption is reported as the percentage increase in weight.

Figure-3.5: Setup for Water absorption test

3.2.5 Water Sorptivity

The sorptivity test is carried out as defined in ASTM C 1585-04 [3]. Sorptivity characterizes the material’s ability to absorb and transmit water through it by capillary suction. Specimens for sorptivity test were painted on all four sides except top and bottom faces to allow only unidirectional uptake of water from the bottom is possible. A curve of cumulative mass gained per exposed surface area was drawn against the square root of time and the slope of the linear portion was considered for determination of sorptivity. The cumulative water absorption (per unit area of the inflow surface) ‘i’ increases as the square root of the elapsed time ‘t’.

$i = S\sqrt{t}$

Where,

‘S’ is the sorptivity measured in g/mm^2 (of wetted area) per min$^{1/2}$. It is determined from the slope of the linear part of ‘i’ versus $\sqrt{t}$ curve.

The detail of experimental set up is shown in Fig.3.6

Figure-3.6: Setup for Water Sorptivity test

3.2.7 X-Ray Diffraction (XRD) Analysis

The X-ray diffraction (XRD) technique offers a convenient way to determine the mineralogical analysis of crystalline solids. If a crystalline mineral is exposed to X-rays of a particular wavelength, the layers of atoms diffract the rays and produce a pattern of peaks, which is characteristic of the mineral. The horizontal scale (diffraction angle) of a typical XRD pattern gives the crystal lattice spacing, and the vertical scale (peak height) gives the intensity of the diffracted ray. When the powder specimen being X-rayed contains more than one mineral the intensity of characteristic peaks from the individual minerals are proportional to their amount. An X-Ray diffraction analysis of powdered specimens will made using a Rigaku Geigerflex D-max II automated diffractometer (Rigaku, Japan) with Cu-Kα radiation with the following conditions: 40 kV, 22.5 mA. The XRD patterns were obtained by scanning at 1° (2θ) per min and in steps of 0.5° (2θ). The slow scanning rate will be used to improve resolution of peaks.

Fig. 3.7 shows a photograph of X-ray diffractometer used in the present research.

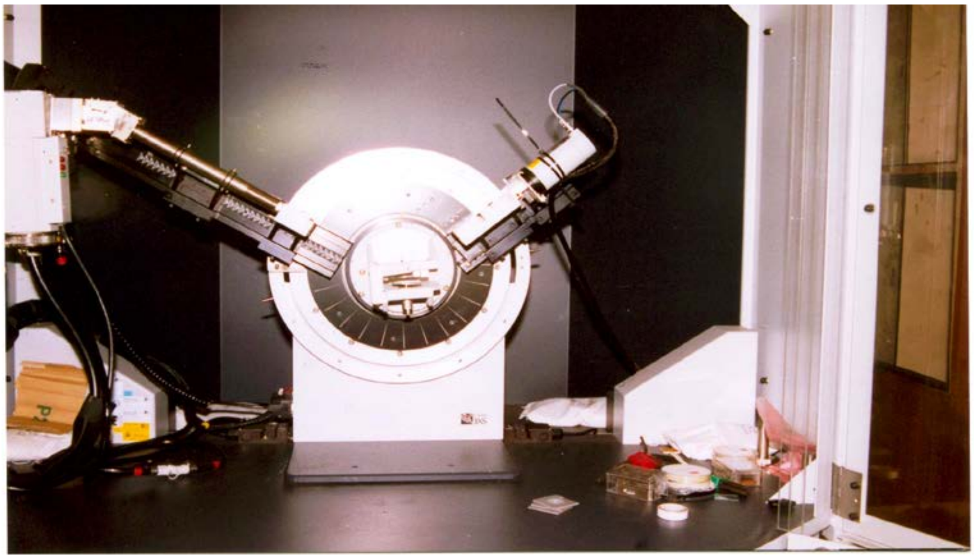


Figure -3.7: A photographs of X-ray Diffractometer

3.2.8 Scanning Electron Microscopy (SEM)

Scanning Electron Micrograph study is used to make qualitative assessment of microstructure. SEM specimens is dried, then gold coated and stored in the desiccators prior to examination using a Joel JSM 5200 as shown in Fig.3.8

Theory

Interaction of the scanning electron microscope electron beam with the specimen surface causes a range of effects where electrons and X-rays are emitted of that generated from the specimen under the beam. The beam is composed of primary electrons, which collide with electrons in orbit around the nuclei of elements present in the specimen. Primary electrons have energy values (up to 40 KeV), and can cause displacement of these secondary electrons, that may subsequently leave the specimen surface and be detected. Secondary electrons do not have high-energy values, compared to backscattered electrons; conventionally bellow 50eV, whereas backscattered electrons have energies ranging from 50eV to that of the primary electrons. Backscattered electrons can therefore be a mixture of high energy secondary electrons knocked out of position by higher energy primary electrons, or primary electrons that have re-emerged from the specimen surface after colliding with and being re-directed by, in-situ electrons that have not been displaced.

If an electron has been knocked out of orbit around an atoms nucleus, and is subsequently replaced by another electron from a lower energy electron shell of the atom, an X-ray can be generated that is characteristic of the element from which it came. The interaction of the beam with the specimen is known as the interaction volume, and is the volume below the surface of the material, in which, primary electrons interact with electrons orbiting around atoms of the material, in which primary material. Secondary electrons are detected from a near surface region of this volume, while backscattered electron can be detected from this and much deeper parts of the specimen. Many electrons escaping from this region are absorbed into the material or not detected at all, as is the case with a small number of x-rays. The range of detected electrons and X-rays is similar in size to the interaction volume as the material less easily absorbs X-rays.

Sample Preparation

SEM examination was made on a cylindrical sample of 10mm diameter and 10mm height approximately that are prepared from the broken samples of GGBFS specimen and immediately gold coated to avoid further chemical reactions. The specimens are stored in the desiccators. So, it is expected that the carbonation effect is insignificant. Also, as all the specimens are prepared in similar condition such effect must be identical in all specimens. The micrographs are obtained at different magnification for the justification of improvement in microstructure of paste samples. This test was done in the University Science and Instrument Center (USIC), Jadavpur University, Kolkata, India.

Figure-3.8: JEOL JSM 5200 Scanning electron microscope

3.2.9 Summary of experimental programme

Table: - Detail of Experimental Programme

Sl. No	Specimen type	Specimen per experiment	Name of the Experiment	Objective of the test
1.	Alkali activated paste	3	Workability	To appreciate workability level of Alkali activated paste.
2	Cube (50mmx50mmx50mm)	3	Compressive strength Test	To get 28 days compressive strength
3	Cube (50mmx50mmx50mm)	3	Sorptivity Test	To appreciate tendency of unidirectional flow through the test specimen
4	Cube (50mmx50mmx50mm)	3	Water absorption	To appreciate the porosity level
5	Cube (50mmx50mmx50mm)	3	Weight loss	To assess the weight loss
6	Cube (50mmx50mmx50mm)	3	Apparent porosity	To appreciate the porosity level
7	Cube (50mmx50mmx50mm)	3	SEM	To study the microstructure of the hardened paste

3.2.10 Detail of mixes

Following table indicated the different mixes which are followed strictly in the laboratory.

Table :- For Unexposed AAGGBFS test specimens of Water/GGBFS=0.35

TEST CHART - 1

SL. NO.	**Mix. ID**	**% Na $_2$ O**	**SiO $_2$ / Na $_2$O**	**Water / GGBS**	**Plasticizer / GGBS**	**Quantity required for a typical mix**				
						Plasticizer	**GGBS**	**Na_2SiO_3**	**H_2O**	**NaOH**
					in %	**gm**	**gm**	***gm***	***gm***	***gm***
1	BFS4-0.8	4%	0.8	0.35	1.3%	13	1000	120.75	262.10	40.32
2	BFS4-1.0	4%	1	0.35	1.3%	13	1000	150.94	243.02	37.11
3	BFS4-1.2	4%	1.2	0.35	1.3%	13	1000	181.13	223.95	33.90
4	BFS6-0.8	6%	0.8	0.35	1.3%	13	1000	181.13	218.15	60.48
5	BFS6-1.0	6%	1	0.35	1.3%	13	1000	226.42	189.54	55.67
6	BFS6-1.2	6%	1.2	0.35	1.3%	13	1000	271.70	160.93	50.85
7	BFS8-0.8	8%	0.8	0.35	1.3%	13	1000	241.51	174.19	80.64
8	BFS8-1.0	8%	1	0.35	1.3%	13	1000	301.89	136.05	74.23
9	BFS8-1.2	8%	1.2	0.35	1.3%	13	1000	362.26	97.91	67.81
10	BFS10-0.8	10%	0.8	0.35	1.3%	13	1000	301.89	130.24	100.81
11	BFS10-1.0	10%	1	0.35	1.3%	13	1000	377.36	82.56	92.78
12	BFS10-1.2	10%	1.2	0.35	1.3%	13	1000	452.83	34.88	84.76

Table:- For Unexposed AAGGBFS test specimens of Water/GGBFS=0.30

TEST CHART - 2

SL. NO.	Mix. ID	% Na $_2$ O	SiO $_2$ / Na $_2$O	Water / GGBS	Plasticizer / GGBS	Quantity required for a typical mix				
						Plasticizer	**GGBS**	**Na_2SiO_3**	**H_2O**	**NaOH**
					in %	**gm**	**gm**	***gm***	***gm***	***gm***
1	BFS4-0.8	4%	0.8	0.3	1.3%	13	1000	120.75	212.10	40.32
2	BFS4-1.0	4%	1	0.3	1.3%	13	1000	150.94	193.02	37.11
3	BFS4-1.2	4%	1.2	0.3	1.3%	13	1000	181.13	173.95	33.90
4	BFS6-0.8	6%	0.8	0.3	1.3%	13	1000	181.13	168.15	60.48
5	BFS6-1.0	6%	1	0.3	1.3%	13	1000	226.42	139.54	55.67
6	BFS6-1.2	6%	1.2	0.3	1.3%	13	1000	271.70	110.93	50.85
7	BFS8-0.8	8%	0.8	0.3	1.3%	13	1000	241.51	124.19	80.64
8	BFS8-1.0	8%	1	0.3	1.3%	13	1000	301.89	86.05	74.23
9	BFS8-1.2	8%	1.2	0.3	1.3%	13	1000	362.26	47.91	67.81
10	BFS10-0.8	10%	0.8	0.3	1.3%	13	1000	301.89	80.24	100.81
11	BFS10-1.0	10%	1	0.3	1.3%	13	1000	377.36	32.56	92.78

Table :- For AAGGBFS test specimens exposed to Sulphuric Acid solution of Water/GGBFS=0.35

SL. NO.	MIX. I.D.	% Na $_2$ O	Water / GGBFS = 0.35	
			Days of exposure to H_2SO_4 soln.	Varying conc. Of H_2SO_4
1	BFS10-0.8	10	7	2%
				4%
				6%
			14	2%
				4%
				6%
			21	2%
				4%
				6%

Table :- For AAGGBFS test specimens exposed to Sulphuric Acid solution of Water/GGBFS=0.30

SL. NO.	MIX. I.D.	% Na_2O	Water / GGBFS = 0.30	
			Days of exposure to H_2SO_4 soln.	Varying conc. Of H_2SO_4
1	BFS8-1.2	8	7	2%
				4%
				6%
			14	2%
				4%
				6%
			21	2%
				4%
				6%
2	BFS10-1.0	10	7	2%
				4%
				6%
			14	2%
				4%
				6%
			21	2%
				4%
				6%

4.1 Preamble

Alkali Activated GGBFS pastes have been tested at fresh state and the Physico-mechanical properties of hardened test specimens have also been measured. Workability, Water Sorptivity, Compressive strength, Water absorption, Specific gravity, Apparent porosity of Alkali Activated GGBFS paste etc. have been recorded and presented in tabular/graphical form. The concentration of alkali (Na_2O) varied from 4% to 10% for SiO_2/Na_2O ratio ranging from 0.8 to 1.2. Dosages of admixture kept 1.3% weight of GGBFS.

Experimental work also includes tests to understand the performance of Alkali Activated pastes specimens exposed to Sulphuric acid solutions of different Concentrations. Alkali/silicate ratio varied from 0.8 to 1.2 and Water /GGBFS ratio varied from 0.35 to 0.30. Similar kind of test as mentioned earlier have been conducted.

4.2 Physico-Mechanical properties of unexposed Alkali Activated Specimens

4.2.1 Workability

4.2.1.1 Effect of Na_2O content

The Workability of Alkali Activated GGBFS paste is determined according to ASTM C-124 using mini slump cone. The diameter of the paste flow is determined in two perpendicular directions immediately after mixing the Alkali Activated GGBFS paste in Mortar mixer. The same test procedure is repeated for another time and the average of the two test results is taken.

The optimum flow diameter of 180-200 mm is considered desirable as the paste can be easily handled and can be placed in the molds effectively.

It is observed that Workability increase with increase in alkali (NaOH) content by the use of Polycarboxylate-based admixture 1.3% weight of GGBFS and Water to GGBS ratio varies from 0.35 to 0.3, the % increase is 5.26% when alkali content increases from 4% to 10% of Water/GGBS ratio is 0.35, the % increase is 28.57% when alkali content increases from 4% to 10% of Water/GGBS ratio is 0.30.

With increase in alkali content in activator solution the rate of reaction of GGBFS paste increases resulting in more gel formation and the resistance to flow of Alkali Activated GGBFS paste increases due to increase in viscosity. So as the alkali content increases the viscosity of flow causing increase in shear resistance to flow and decrease in workability but use of admixture modify viscosity and increase workability at certain extent.

Table 4.2.1.1.1 Workability for Alkali series with Water/GGBFS = 0.35

Water / GGBFS = 0.35					
Alkali (NaOH) content in %		4%	6%	8%	10%
Admixture	Retarding	1.3% wt. of GGBFS			
	Water reducing				
	VMA				
Workability based on flow value in mm.		190	200	200	200

Table 4.2.1.1.2 Workability for Alkali series with Water/GGBFS = 0.30

Water / GGBFS = 0.30					
Alkali (NaOH) content in %		4%	6%	8%	10%
Admixture	Retarding	1.3% wt. of GGBFS			
	Water reducing				
	VMA				
Workability based on flow value in mm.		175	180	200	225

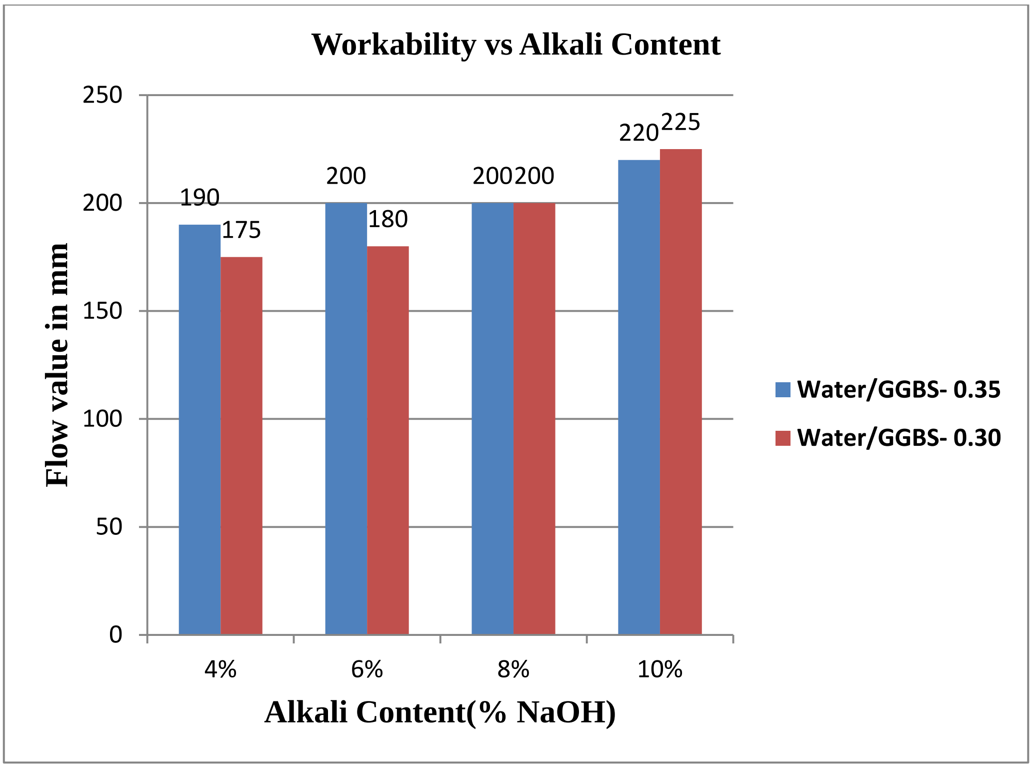


Figure 4.2.1.1.1

Effect of Na_2O content on Workability of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.35 and 0.30

4.2.1.2. Effect of SiO_2 content

The effect of the Silicate ratio (SiO_2/Na_2O) on the Workability of blast furnace slag paste is shown in figure below at water/GGBFS=0.35 and 0.30. The Na_2O content varies from 4% to 10% and silicate ratio (SiO_2/Na_2O) varies from 0.8 to 1.2 respectively. The result shown that flow diameter increases in silicate content from 150 to 220 mm at water/GGBFS= 0.35 and 120 to 200 mm at Water/GGBFS= 0.30 for silicate ratio varies from 0.8 to 1.2. Increasing the amount of the liquid alkaline solution increases the water content in the reaction medium which results in the large inter-particle distance and subsequently reduces the friction between the particles [26], resulting in an increase in flow diameter. Maximum flow value is 220 mm at silicate ratio 1.2 and Water/GGBFS=0.35, 225 mm at silicate ratio 1.0 and Water/GGBFS=0.30.

Table 4.2.1.2.1 Workability for Silicate ratio with Water/GGBFS is 0.35 and 0.30

Silicate ratio (SiO_2 / Na_2O)	Water / GGBS = 0.35	Water / GGBS = 0.30
	Workability based on Flow Value in mm.	Workability based on Flow Value in mm.
0.8	170	120
1	175	130
1.2	190	175
0.8	195	140
1	200	170
1.2	200	180
0.8	150	150
1	170	185
1.2	200	200
0.8	185	170
1	200	225
1.2	220	

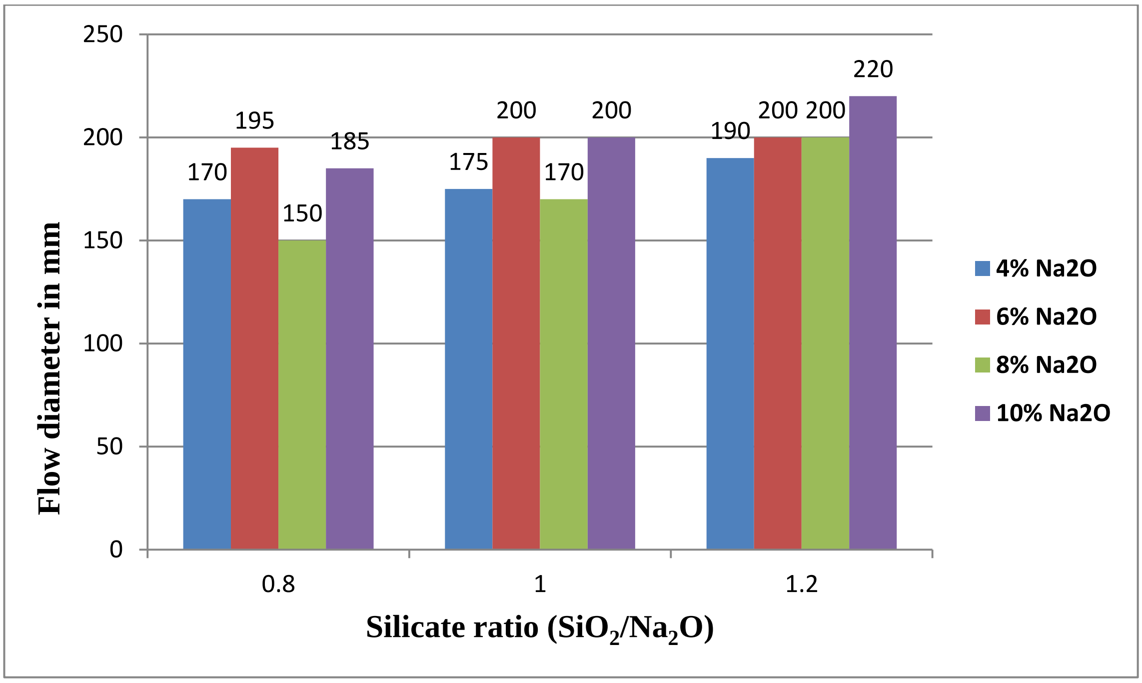


Figure 4.2.1.2.1

Effect of Silicate ratio (SiO_2/Na_2O) on Flow diameter of unexposed Alkali Activated GGBFS paste with Water/GGBFS=0.35.

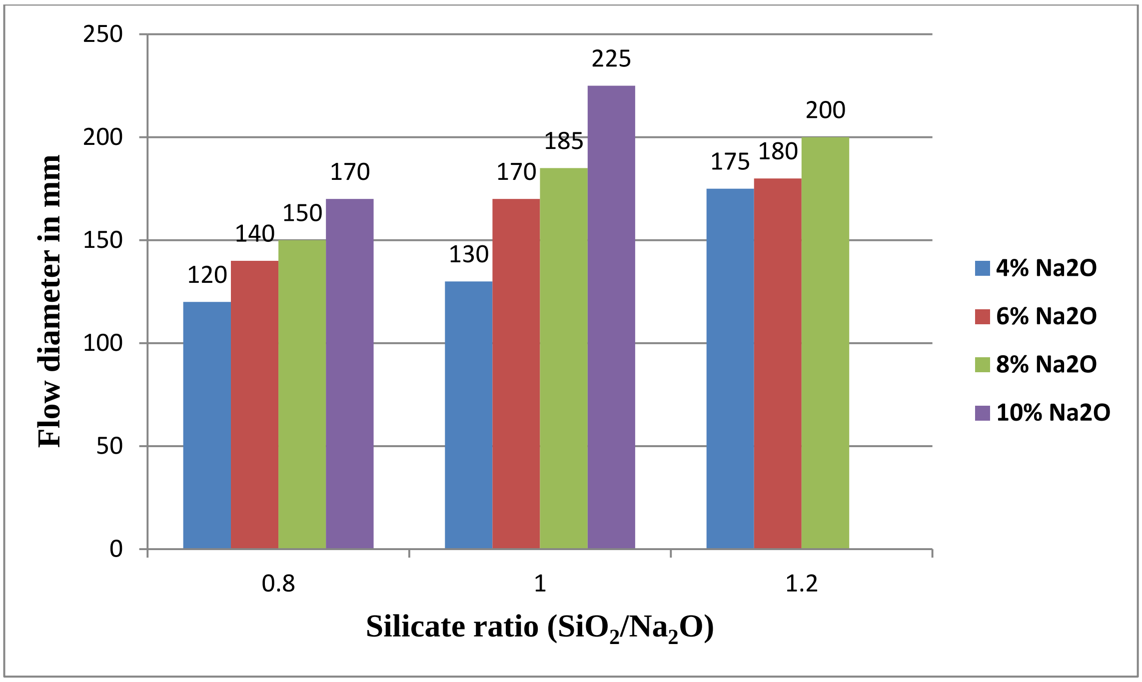


Figure 4.2.1.2.2

Effect of Silicate ratio (SiO_2/Na_2O) on Flow diameter of unexposed Alkali Activated GGBFS paste with Water/GGBFS=0.30.

4.2.2 Water Sorptivity

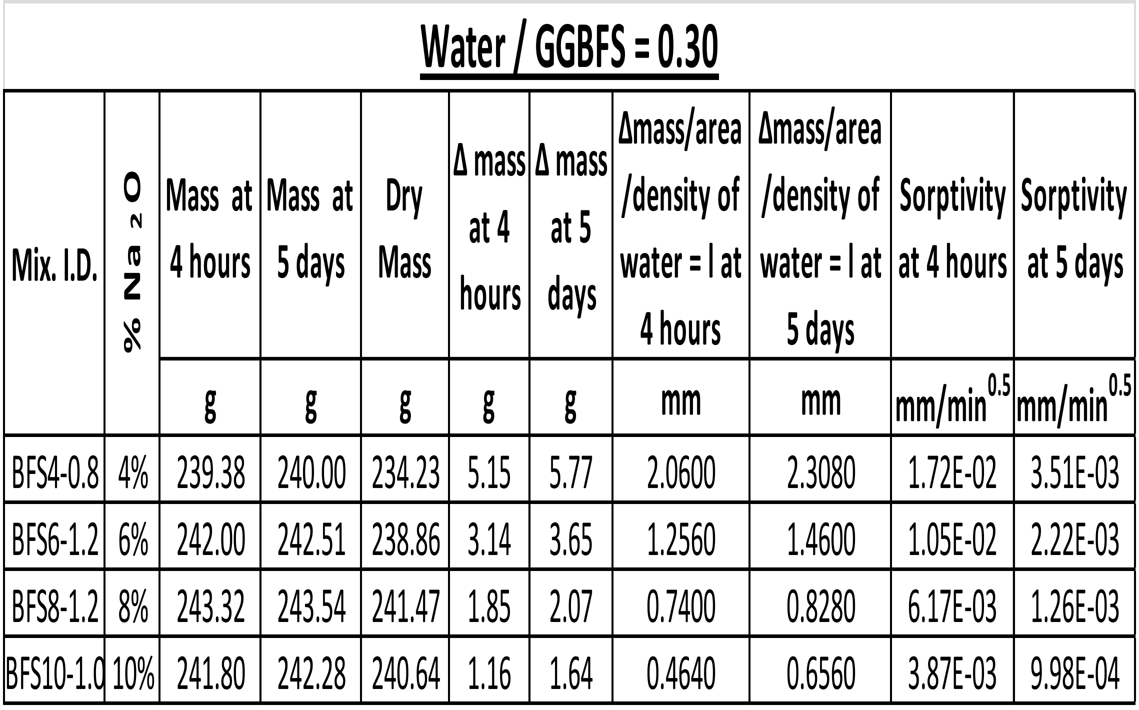
4.2.2.1 Effect of Na_2O content

The Water Sorptivity of Alkali Activated GGBFS paste is determined according to ASTM C 1585-04. Generally the quality of alkali activated composites is measured by the compressive strength. But strength is not the standard and proper parameter to assess the quality of alkali activated composites in terms of durability. The characteristic of pore structure can be assessed by measuring the rate of unidirectional capillary absorption of water by unsaturated Alkali Activated GGBFS paste when placed in contact with water when no head of water exists, is known as Sorptivity. Sorptivity measurement has primary importance in durability assessment of Alkali Activated GGBFS paste.

The cumulative increase in mass of Alkali Activated GGBFS paste due to unidirectional capillary water absorption with square root of time is shown in Figures below. Initial rate of water absorption through capillarity is almost linear up to 4 hrs is called initial absorption. After four hours the unsaturated alkali activated GGBFS paste gets almost saturated and less amount of water absorption occurs up to 5 days is called secondary absorption. It is observed that cumulative water absorption decreases with increasing percentage of alkali (NaOH). From the graphical representation below it is observed that Water Sorptivity is more at lower alkali content (4% Na_2O). Water Sorptivity decreases with increase in alkali content from 4% to 10% for Water / GGBFS ratio 0.30 and 0.35 respectively.

The Sorptivity decreases with increase in alkali content because as alkali content increases the rate of reaction of GGBFS with activator solution also increases resulting in more gel formation which makes the Alkali Activated GGBFS pastes more compact thus containing less pore space up to 10%.

Table 4.2.2.1 Water Sorptivity for Alkali series with Water/GGBFS = 0.30



Water / GGBFS = 0.30

Mix. I.D.	% Na_2O	Mass at 4 hours	Mass at 5 days	Dry Mass	Δ mass at 4 hours	Δ mass at 5 days	Δmass/area /density of water = I at 4 hours	Δmass/area /density of water = I at 5 days	Sorptivity at 4 hours	Sorptivity at 5 days
		g	g	g	g	g	mm	mm	$mm/min^{0.5}$	$mm/min^{0.5}$
BFS4-0.8	4%	239.38	240.00	234.23	5.15	5.77	2.0600	2.3080	1.72E-02	3.51E-03
BFS6-1.2	6%	242.00	242.51	238.86	3.14	3.65	1.2560	1.4600	1.05E-02	2.22E-03
BFS8-1.2	8%	243.32	243.54	241.47	1.85	2.07	0.7400	0.8280	6.17E-03	1.26E-03
BFS10-1.0	10%	241.80	242.28	240.64	1.16	1.64	0.4640	0.6560	3.87E-03	9.98E-04

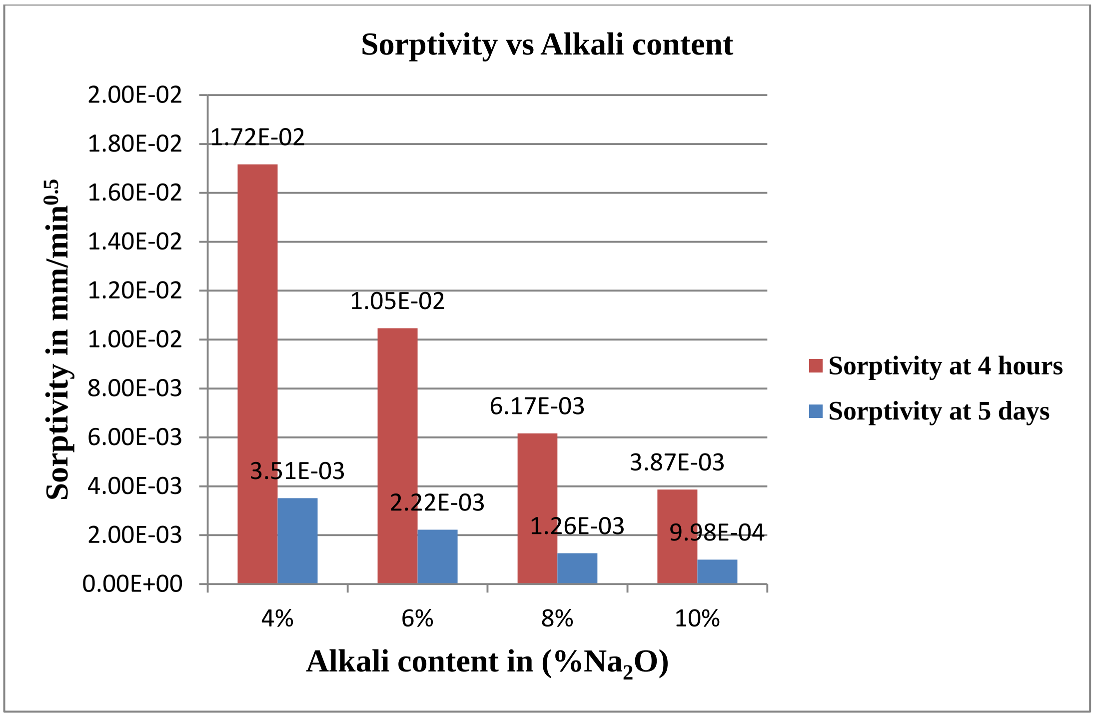


Figure 4.2.2.1

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste with Water/GGBFS=0.30

Table 4.2.2.1.1 Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 4% NaOH with Water/GGBFS = 0.30

Time (t)		√ Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area/ density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm^2	mm	$mm/min^{0.5}$
0	0	0	BFS4 -0.8 (W/B = 0.3)	234.23	234.23	0.00	2500	0.0000	0.0000000
60	1 min.	8		234.70	234.23	0.47	2500	0.1880	0.0320167
300	5 min.	17		235.00	234.23	0.77	2500	0.3080	0.0177824
600	10 min.	24		235.27	234.23	1.04	2500	0.4160	0.0169831
1200	20 min.	35		235.74	234.23	1.51	2500	0.6040	0.0174360
1800	30 min.	42		236.26	234.23	2.03	2500	0.8120	0.0191390
3600	1 hr	60		237.12	234.23	2.89	2500	1.1560	0.0192667
7200	2 hr	85		238.01	234.23	3.78	2500	1.5120	0.0178191
10800	3 hr	104		239.17	234.23	4.94	2500	1.9760	0.0190141
14400	4 hr	120		239.38	234.23	5.15	2500	2.0600	1.72E-02
18000	5 hr	134		239.51	234.23	5.28	2500	2.1120	0.0157419
21600	6 hr	147		239.55	234.23	5.32	2500	2.1280	0.0144792
92220	1 day	304		239.83	234.23	5.60	2500	2.2400	0.0075080
193200	2 days	440		239.94	234.23	5.71	2500	2.2840	0.0051963
268500	3 days	518		239.95	234.23	5.72	2500	2.2880	0.0044155
432000	5 days	657		240.00	234.23	5.77	2500	2.3080	0.0034689

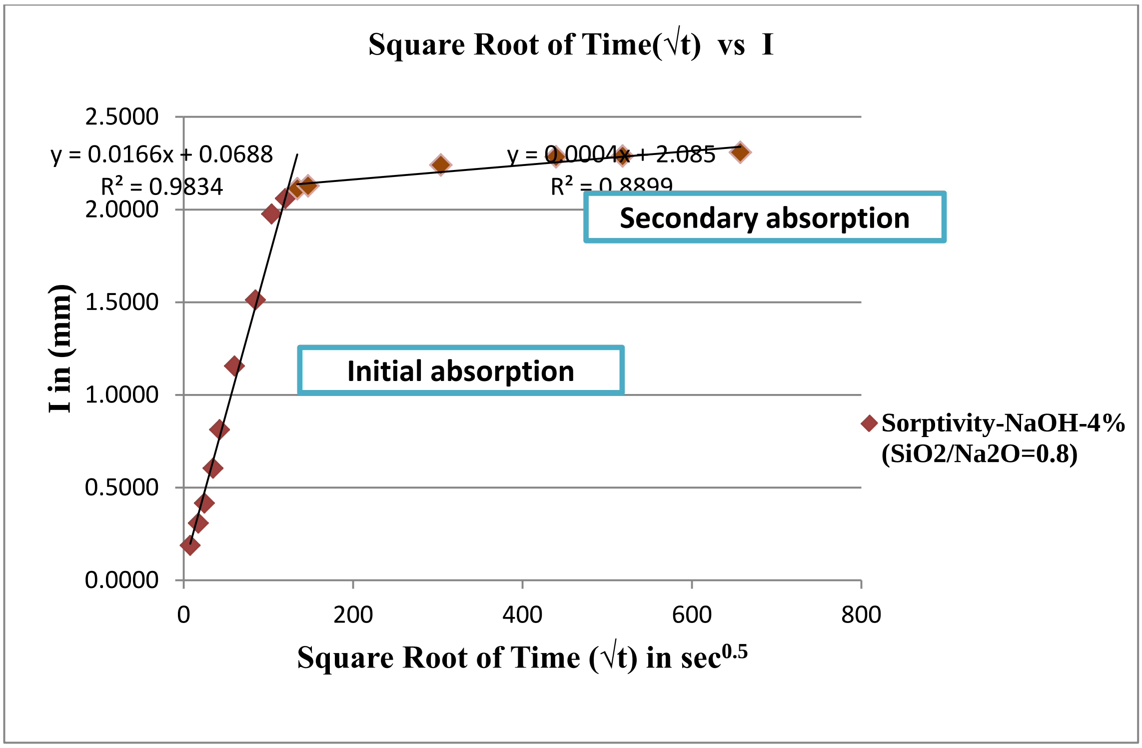


Figure 4.2.2.1.1

Effect of Na$_2$O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 4% NaOH with Water/GGBFS = 0.30

Table 4.2.2.1.2 Effect of Na$_2$O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 6% NaOH with Water/GGBFS = 0.30

Time (t)		√Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area/ density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm^2	mm	mm/min$^{0.5}$
0	0	0	BFS6 -1.2 (W/B = 0.3)	238.86	238.86	0.00	2500	0.0000	0.0000000
60	1 min.	8		239.08	238.86	0.22	2500	0.0880	0.0113608
300	5 min.	17		239.15	238.86	0.29	2500	0.1160	0.0066973
600	10 min.	24		239.27	238.86	0.41	2500	0.1640	0.0066953
1200	20 min.	35		239.41	238.86	0.55	2500	0.2200	0.0063509
1800	30 min.	42		239.71	238.86	0.85	2500	0.3400	0.0080139
3600	1 hr	60		240.22	238.86	1.36	2500	0.5440	0.0090667
7200	2 hr	85		240.92	238.86	2.06	2500	0.8240	0.0097109
10800	3 hr	104		241.48	238.86	2.62	2500	1.0480	0.0100844
14400	4 hr	120		242.00	238.86	3.14	2500	1.2560	0.0104667
18000	5 hr	134		242.06	238.86	3.20	2500	1.2800	0.0093915
21600	6 hr	147		242.12	238.86	3.26	2500	1.3040	0.0088726
92220	1 day	304		242.32	238.86	3.46	2500	1.3840	0.00455747
193200	2 days	440		242.38	238.86	3.52	2500	1.4080	0.00311231
268500	3 days	518		242.45	238.86	3.59	2500	1.4360	0.00277129
432000	5 days	657		242.51	238.86	3.65	2500	1.4600	0.00222132

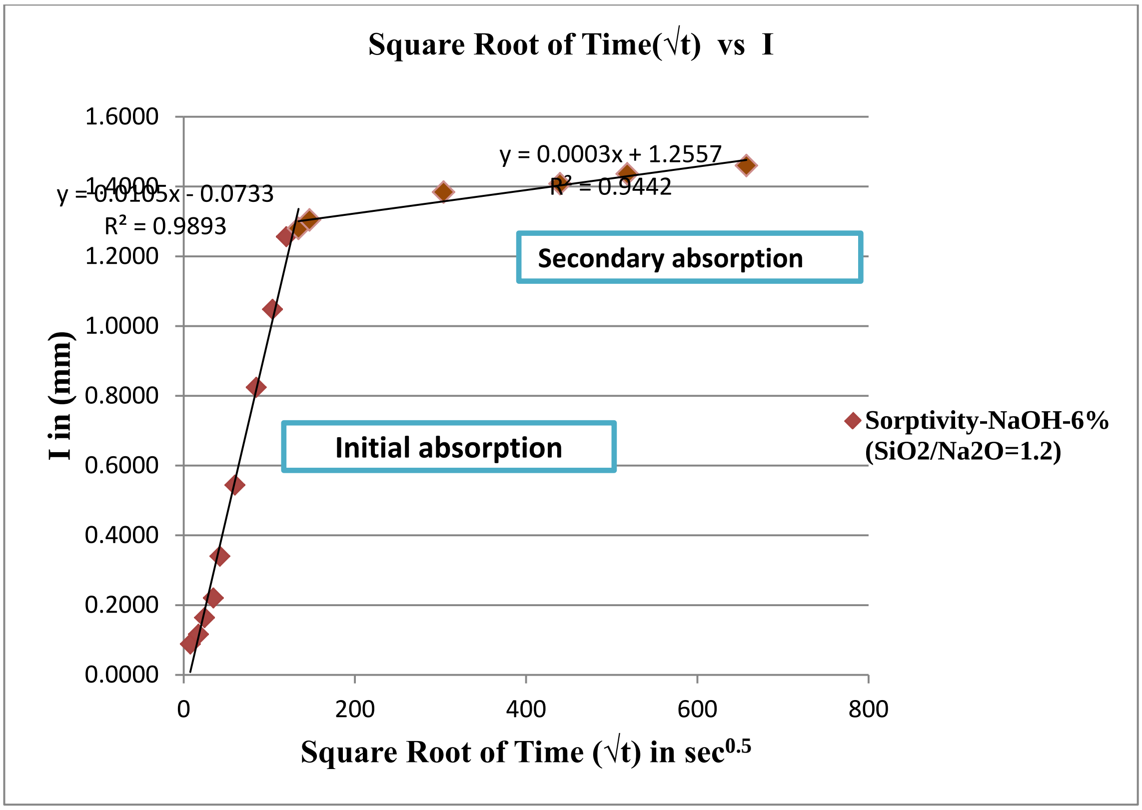


Figure 4.2.2.1.2

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 6% NaOH with Water/GGBFS = 0.30

Table 4.2.2.1.3 Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 8% NaOH with Water/GGBFS = 0.30

Time (t)		√ Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area/ density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm^2	mm	$mm/min^{0.5}$
0	0	0	BFS8- 1.2 (W/B = 0.3)	241.47	241.47	0.00	2500	0.0000	0
60	1 min.	8		241.76	241.47	0.29	2500	0.1160	0.0149755
300	5 min.	17		241.83	241.47	0.36	2500	0.1440	0.0083138
600	10 min.	24		241.95	241.47	0.48	2500	0.1920	0.0078384
1200	20 min.	35		242.07	241.47	0.60	2500	0.2400	0.0069282
1800	30 min.	42		242.23	241.47	0.76	2500	0.3040	0.0071653
3600	1 hr	60		242.47	241.47	1.00	2500	0.4000	0.0066667
7200	2 hr	85		242.79	241.47	1.32	2500	0.5280	0.0062225
10800	3 hr	104		243.05	241.47	1.58	2500	0.6320	0.0060814
14400	4 hr	120		243.32	241.47	1.85	2500	0.7400	0.0061667
18000	5 hr	134		243.39	241.47	1.92	2500	0.7680	0.0057243
21600	6 hr	147		243.40	241.47	1.93	2500	0.7720	0.0052528
92220	1 day	304		243.45	241.47	1.98	2500	0.7920	0.002608
193200	2 days	440		243.47	241.47	2.00	2500	0.8000	0.0018201
268500	3 days	518		243.49	241.47	2.02	2500	0.8080	0.0015593
432000	5 days	657		243.54	241.47	2.07	2500	0.8280	0.0013206

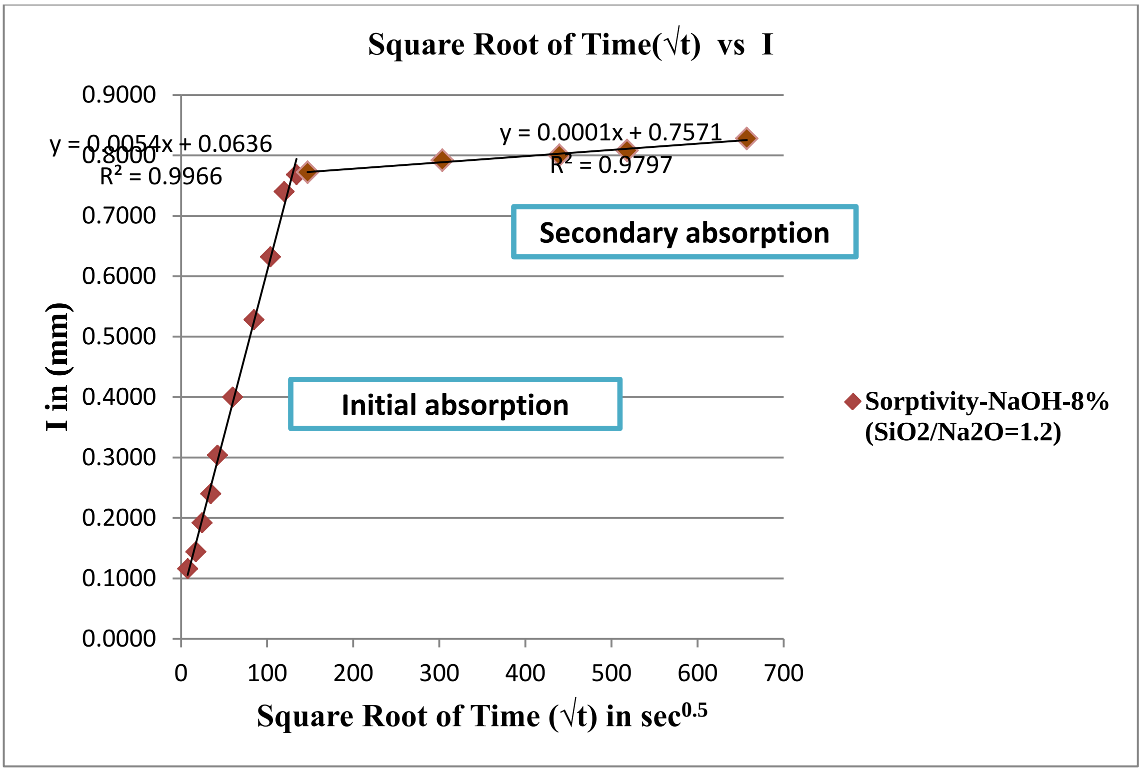


Figure 4.2.2.1.3

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 8% NaOH with Water/GGBFS = 0.30

Table 4.2.2.1.4 Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 10% NaOH with Water/GGBFS = 0.30

Time (t)		√ Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area /density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm²	mm	mm/min$^{0.5}$
0	0	0	BFS10 -1.0 (W/B = 0.3)	240.64	240.64	0.00	2500	0.0000	0.0000000
60	1 min.	8		240.89	240.64	0.25	2500	0.1000	0.01290994
300	5 min.	17		240.91	240.64	0.27	2500	0.1080	0.00623538
600	10 min.	24		241.00	240.64	0.36	2500	0.1440	0.00587878
1200	20 min.	35		241.07	240.64	0.43	2500	0.1720	0.00496521
1800	30 min.	42		241.17	240.64	0.53	2500	0.2120	0.00499689
3600	1 hr	60		241.30	240.64	0.66	2500	0.2640	0.0044000
7200	2 hr	85		241.45	240.64	0.81	2500	0.3240	0.00381838
10800	3 hr	104		241.62	240.64	0.98	2500	0.3920	0.00377202
14400	4 hr	120		241.80	240.64	1.16	2500	0.4640	0.00386667
18000	5 hr	134		241.87	240.64	1.23	2500	0.4920	0.00366715
21600	6 hr	147		241.88	240.64	1.24	2500	0.4960	0.00337485
92220	1 day	304		242.02	240.64	1.38	2500	0.5520	0.00181772
193200	2 days	440		242.12	240.64	1.48	2500	0.5920	0.00134685
268500	3 days	518		242.18	240.64	1.54	2500	0.6160	0.0011888
432000	5 days	657		242.28	240.64	1.64	2500	0.6560	0.00078507

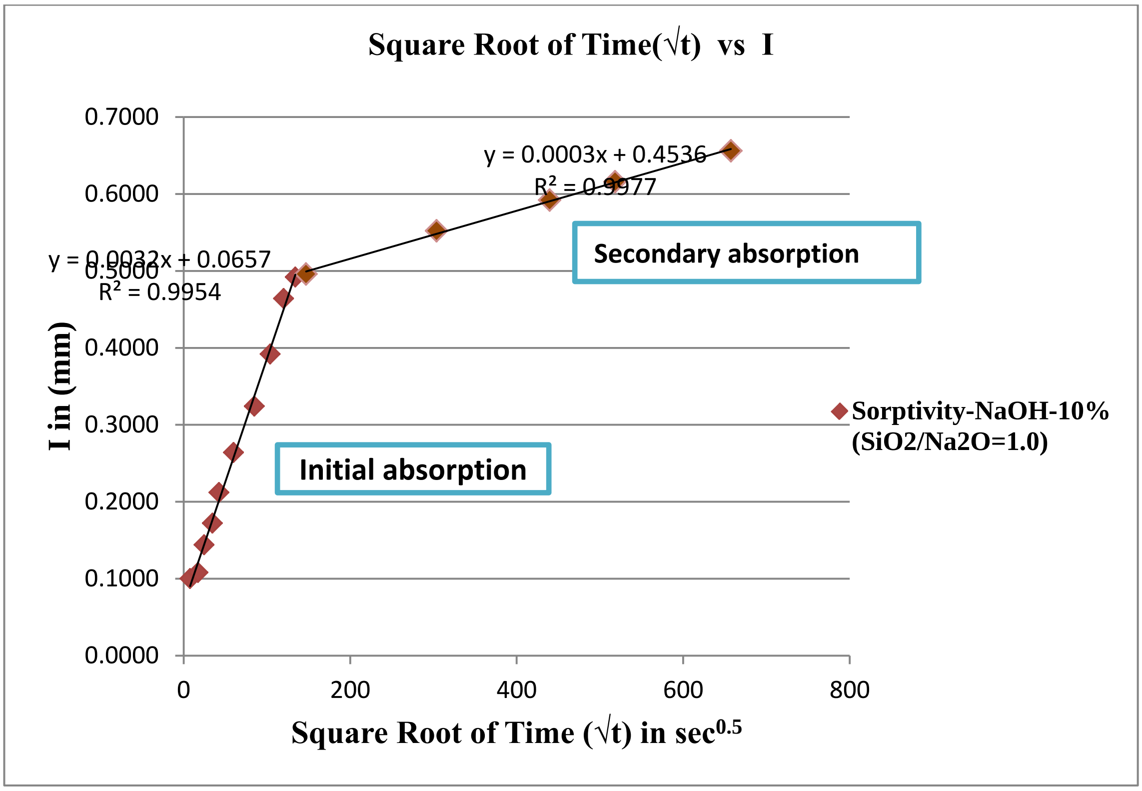


Figure 4.2.2.1.4

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 10% NaOH with Water/GGBFS = 0.30

Table 4.2.2.2 Water Sorptivity for Alkali series with Water/GGBFS = 0.35

Water / GGBFS = 0.35

Mix. I.D.	% Na_2O	Mass at 4 hours	Mass at 5 days	Dry Mass	Δ mass at 4 hours	Δ mass at 5 days	Δmass/area /density of water = I at 4 hours	Δmass/area /density of water = I at 5 days	Sorptivity at 4 hours	Sorptivity at 5 days
		g	g	g	g	g	mm	mm	$mm/min^{0.5}$	$mm/min^{0.5}$
BFS4-0.8	4%	223.14	226.98	189.00	34.14	37.98	13.6560	15.1920	1.14E-01	2.31E-02
BFS6-0.8	6%	231.83	232.55	220.10	11.73	12.45	4.6920	4.9800	3.91E-02	7.58E-03
BFS8-0.8	8%	231.13	233.22	226.26	4.87	6.96	1.9480	2.7840	1.62E-02	4.24E-03
BFS10-0.8	10%	244.82	246.30	240.63	4.19	5.67	1.6760	2.2680	1.40E-02	3.45E-03

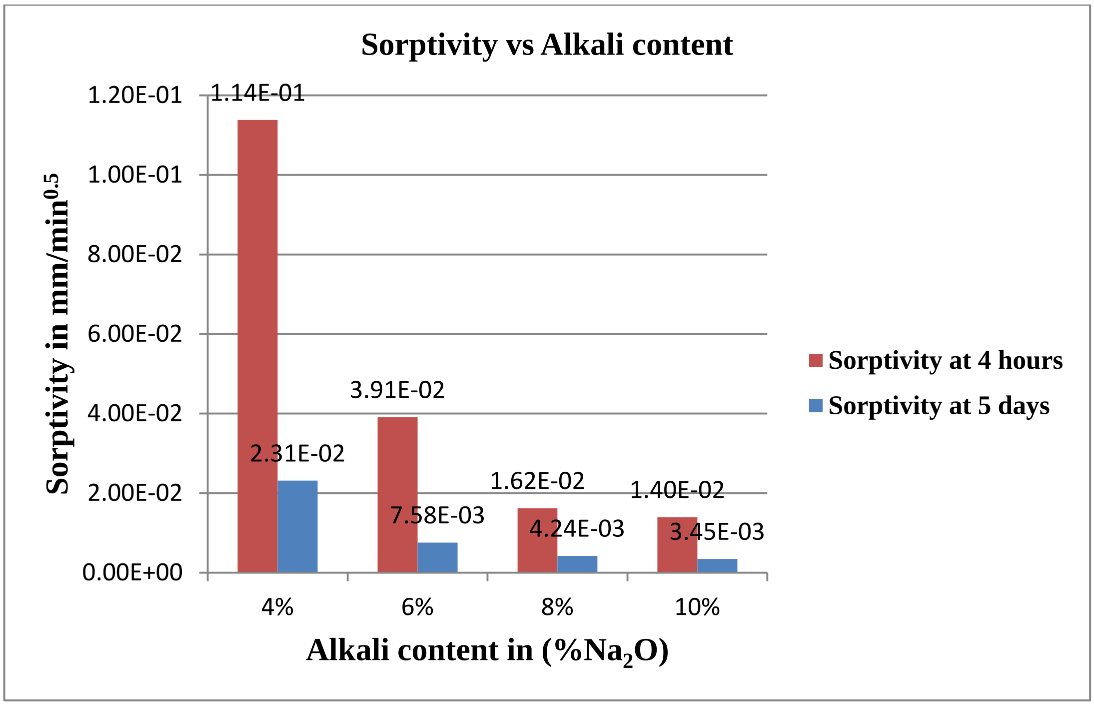


Figure 4.2.2.2

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.35

Table 4.2.2.2.1 Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 4% NaOH with Water/GGBFS = 0.35

Time (t)		√ Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area /density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm^2	mm	$mm/min^{0.5}$
0	0	0	BFS4 -0.8 (W/B = 0.35)	189.00	189.00	0.00	2500	0.0000	0.0000000
60	1 min.	8		198.91	189.00	9.91	2500	3.9640	0.5117502
300	5 min.	17		204.24	189.00	15.24	2500	6.0960	0.3519527
600	10 min.	24		212.60	189.00	23.60	2500	9.4400	0.3853864
1200	20 min.	35		221.71	189.00	32.71	2500	13.0840	0.3777025
1800	30 min.	42		222.23	189.00	33.23	2500	13.2920	0.3132954
3600	1 hr	60		222.43	189.00	33.43	2500	13.3720	0.2228667
7200	2 hr	85		222.71	189.00	33.71	2500	13.4840	0.1589105
10800	3 hr	104		222.91	189.00	33.91	2500	13.5640	0.1305197
14400	4 hr	120		223.14	189.00	34.14	2500	13.6560	0.1138000
18000	5 hr	134		223.26	189.00	34.26	2500	13.7040	0.1021436
21600	6 hr	147		223.44	189.00	34.44	2500	13.7760	0.0937338
92220	1 day	304		224.18	189.00	35.18	2500	14.0720	0.0463386
193200	2 days	440		225.11	189.00	36.11	2500	14.4440	0.0328612
268500	3 days	518		226.08	189.00	37.08	2500	14.8320	0.0286238
432000	5 days	657		226.98	189.00	37.98	2500	15.1920	0.0216046

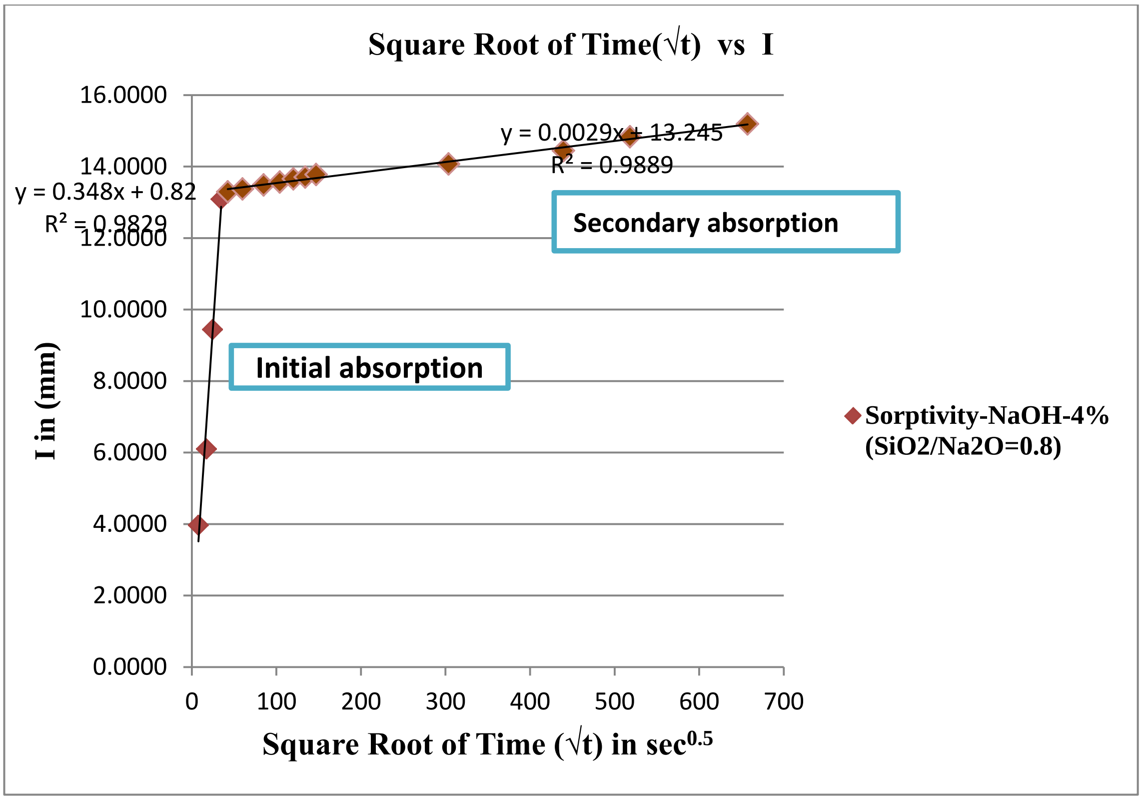


Figure 4.2.2.2.1

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 4% NaOH with Water/GGBFS = 0.35

Table 4.2.2.2.2 Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 6% NaOH with Water/GGBFS = 0.35

Time (t)		√Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area/ density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm^2	mm	$mm/min^{0.5}$
0	0	0	BFS6 -0.8 (W/B = 0.35)	220.10	220.10	0.00	2500	0.0000	0.00000000
60	1 min.	8		222.09	220.10	1.99	2500	0.7960	0.10276316
300	5 min.	17		224.03	220.10	3.93	2500	1.5720	0.09075946
600	10 min.	24		224.86	220.10	4.76	2500	1.9020	0.07764882
1200	20 min.	35		225.85	220.10	5.75	2500	2.3000	0.06639528
1800	30 min.	42		227.04	220.10	6.94	2500	2.7740	0.06538381
3600	1 hr	60		228.60	220.10	8.50	2500	3.4000	0.05666667
7200	2 hr	85		230.13	220.10	10.03	2500	4.0100	0.04725830
10800	3 hr	104		231.07	220.10	10.97	2500	4.3860	0.04220430
14400	4 hr	120		231.83	220.10	11.73	2500	4.6900	0.03908333
18000	5 hr	134		232.08	220.10	11.98	2500	4.7900	0.03570255
21600	6 hr	147		232.22	220.10	12.12	2500	4.8460	0.03297285
92220	1 day	304		232.28	220.10	12.18	2500	4.8720	0.01604334
193200	2 days	440		232.53	220.10	12.43	2500	4.9700	0.01130714
268500	3 days	518		232.54	220.10	12.44	2500	4.9760	0.00960303
432000	5 days	657		232.55	220.10	12.45	2500	4.9780	0.00757379

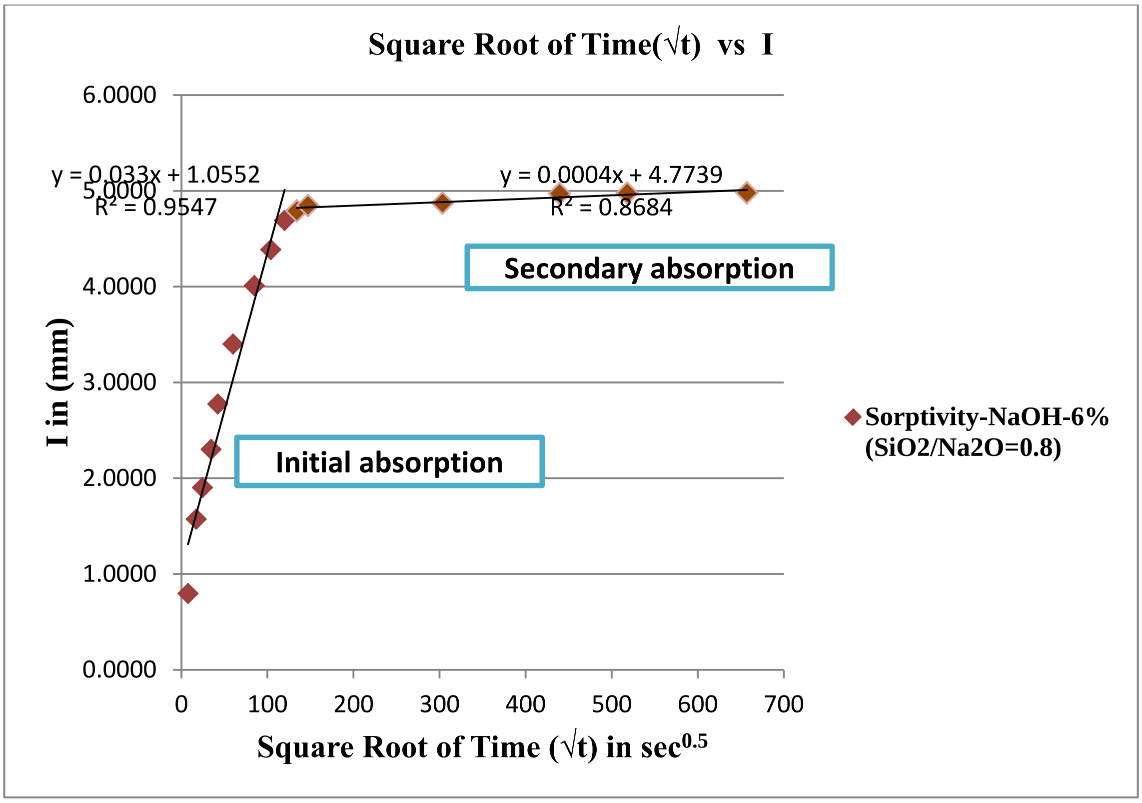


Figure 4.2.2.2.2

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 6% NaOH with Water/GGBFS = 0.35

Table 4.2.2.2.3 Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 8% NaOH with Water/GGBFS = 0.35

Time (t)		√ Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area/ density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm^2	mm	$mm/min^{0.5}$
0	0	0	BFS8 -0.8 (W/B = 0.35)	226.26	226.26	0.00	2500	0.0000	0.00000000
60	1 min.	8		227.15	226.26	0.89	2500	0.3560	0.04595940
300	5 min.	17		227.54	226.26	1.28	2500	0.5120	0.02956033
600	10 min.	24		227.80	226.26	1.54	2500	0.6160	0.02514809
1200	20 min.	35		228.07	226.26	1.81	2500	0.7220	0.02084234
1800	30 min.	42		228.39	226.26	2.13	2500	0.8500	0.02003469
3600	1 hr	60		228.85	226.26	2.59	2500	1.0360	0.01726667
7200	2 hr	85		229.52	226.26	3.26	2500	1.3020	0.01534422
10800	3 hr	104		230.40	226.26	4.14	2500	1.6560	0.01593487
14400	4 hr	120		231.13	226.26	4.87	2500	1.9460	0.01621667
18000	5 hr	134		231.93	226.26	5.67	2500	2.2660	0.01688977
21600	6 hr	147		232.27	226.26	6.01	2500	2.4020	0.01634354
92220	1 day	304		232.87	226.26	6.61	2500	2.6440	0.00870661
193200	2 days	440		233.15	226.26	6.89	2500	2.7560	0.00627012
268500	3 days	518		233.18	226.26	6.92	2500	2.7680	0.00534188
432000	5 days	657		233.22	226.26	6.95	2500	2.7820	0.00423268

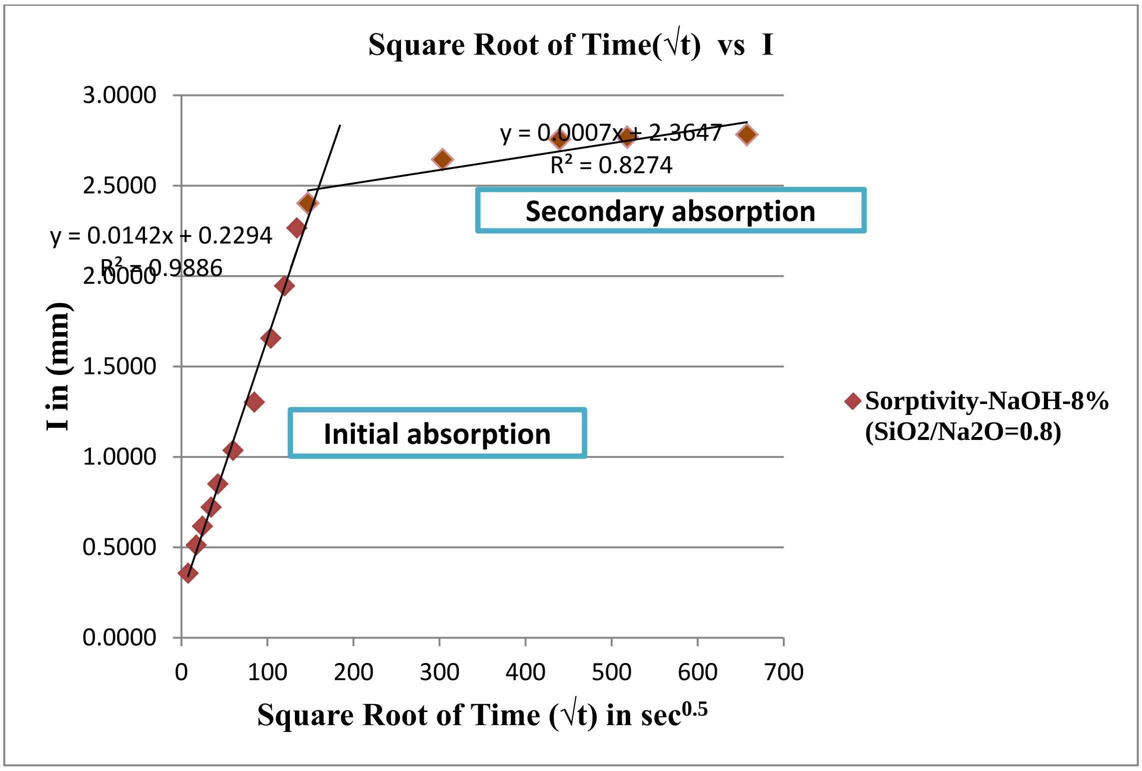


Figure 4.2.2.2.3

Effect of Na$_2$O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 8% NaOH with Water/GGBFS = 0.35

Table 4.2.2.2.4 Effect of Na$_2$O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 10% NaOH with Water/GGBFS = 0.35

Time (t)		√ Time	Mix. I.D.	Mass	Mass after sealing specimen	Δ mass	Area	Δmass/area/ density of water = I	Sorptivity
Sec.	min. / hr.	√t		g	g	g	mm^2	mm	mm/min$^{0.5}$
0	0	0	BFS10 -0.8 (W/B = 0.35)	240.63	240.63	0.00	2500	0.0000	0.00000000
60	1 min.	8		240.83	240.63	0.21	2500	0.0820	0.01058615
300	5 min.	17		240.97	240.63	0.34	2500	0.1360	0.00785196
600	10 min.	24		241.81	240.63	1.18	2500	0.4720	0.01926932
1200	20 min.	35		242.37	240.63	1.75	2500	0.6980	0.02014952
1800	30 min.	42		242.93	240.63	2.30	2500	0.9200	0.02168461
3600	1 hr	60		243.51	240.63	2.88	2500	1.1540	0.01923333
7200	2 hr	85		244.18	240.63	3.56	2500	1.4220	0.01675843
10800	3 hr	104		244.60	240.63	3.97	2500	1.5880	0.01528054
14400	4 hr	120		244.82	240.63	4.19	2500	1.6780	0.013983333
18000	5 hr	134		245.00	240.63	4.38	2500	1.7500	0.01304373
21600	6 hr	147		245.05	240.63	4.42	2500	1.7680	0.01202972
92220	1 day	304		245.35	240.63	4.72	2500	1.8880	0.00621712
193200	2 days	440		245.50	240.63	4.87	2500	1.9480	0.00443185
268500	3 days	518		245.93	240.63	5.31	2500	2.1220	0.00409518
432000	5 days	657		246.30	240.63	5.67	2500	2.2680	0.003450652

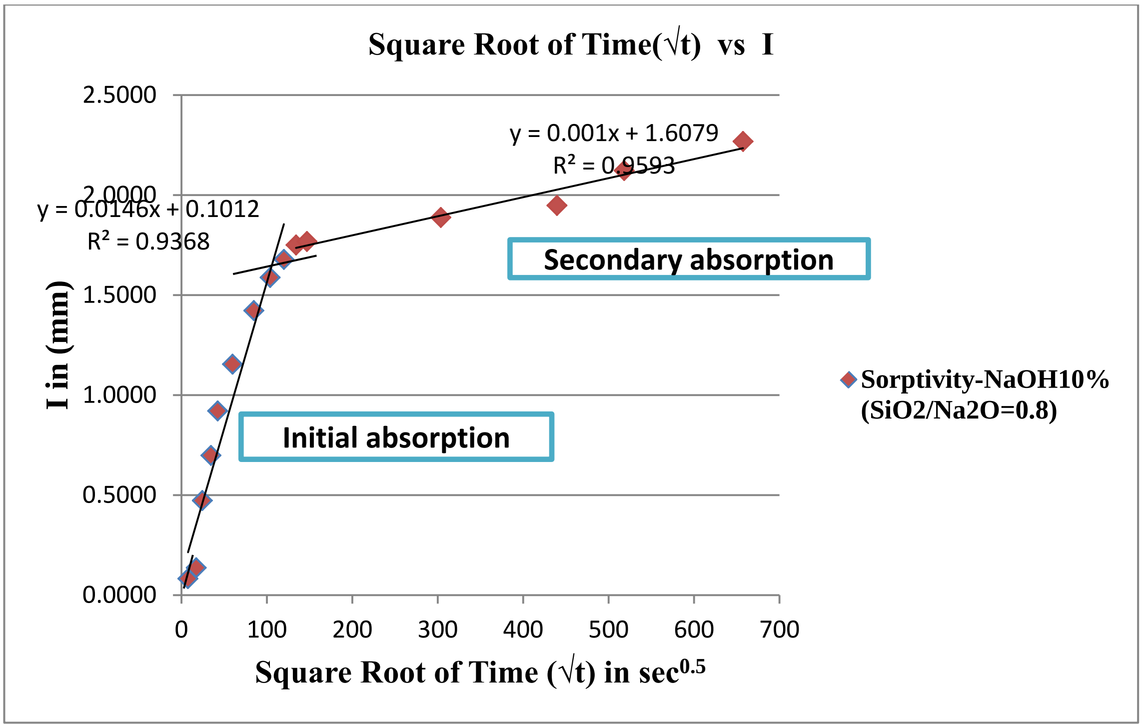


Figure 4.2.2.2.4

Effect of Na_2O content on Water Sorptivity of unexposed Alkali Activated GGBFS paste at 10% NaOH with Water/GGBFS = 0.35

It has been observed that the initial rate of absorption (*Si*) and secondary rate of absorption (*Ss*) decreases with increase in alkali content varies from 4% to 10% at Water/GGBFS is 0.35 and 0.30 respectively.

Table 4.2.2..3 Effect of Na_2O content on Sorptivity ratio of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.30

Water / GGBFS = 0.30											
Mix. I.D.	% Na_2O	Mass at 4 hours	Mass at 5 days	Dry Mass	Δ mass at 4 hours	Δ mass at 5 days	Δmass/area /density of water = I at 4 hours	Δmass/area /density of water = I at 5 days	Initial Sorptivity	Final Sorptivity	S_i/S_s
		g	g	g	g	g	mm	mm	$mm/min^{0.5}$	$mm/min^{0.5}$	
BFS4-0.8	4%	239.38	240.00	234.23	5.15	5.77	2.0600	2.3080	1.72E-02	3.51E-03	4.89
BFS6-1.2	6%	242.00	242.51	238.86	3.14	3.65	1.2560	1.4600	1.05E-02	2.22E-03	4.71
BFS8-1.2	8%	243.32	243.54	241.47	1.85	2.07	0.7400	0.8280	6.17E-03	1.26E-03	4.89
BFS10-1.0	10%	241.80	242.28	240.64	1.16	1.64	0.4640	0.6560	3.87E-03	9.98E-04	3.87

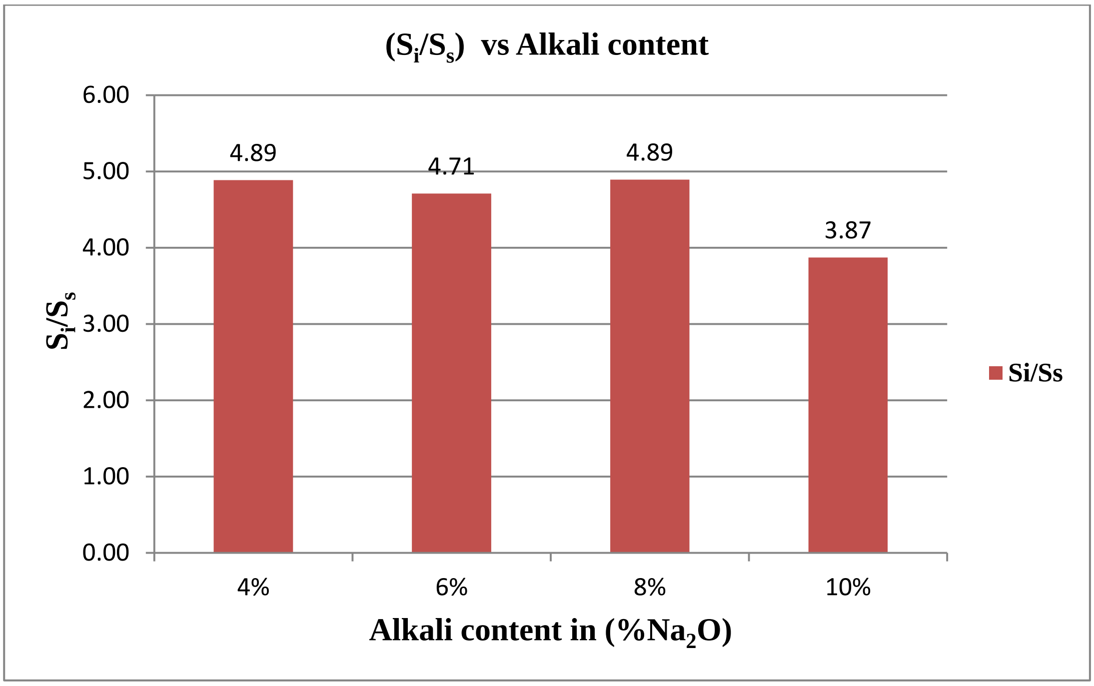


Figure 4.2.2.3

Effect of Na_2O content on Water Sorptivity ratio of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.30

Table 4.2.2..4 Effect of Na_2O content on Sorptivity ratio of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.35

Water / GGBFS = 0.35

Mix. I.D.	% Na_2O	Mass at 4 hours	Mass at 5 days	Dry Mass	Δ mass at 4 hours	Δ mass at 5 days	Δmass/area /density of water = I at 4 hours	Δmass/area /density of water = I at 5 days	Initial Sorptivity	Final Sorptivity	S_i/S_s
		g	g	g	g	g	mm	mm	$mm/min^{0.5}$	$mm/min^{0.5}$	
BFS4-0.8	4%	223.14	226.98	189.00	34.14	37.98	13.6560	15.1920	1.14E-01	2.31E-02	4.92
BFS6-0.8	6%	231.83	232.55	220.10	11.73	12.45	4.6920	4.9800	3.91E-02	7.58E-03	5.16
BFS8-0.8	8%	231.13	233.22	226.26	4.87	6.96	1.9480	2.7840	1.62E-02	4.24E-03	3.83
BFS10-0.8	10%	244.82	246.30	240.63	4.19	5.67	1.6760	2.2680	1.40E-02	3.45E-03	4.05

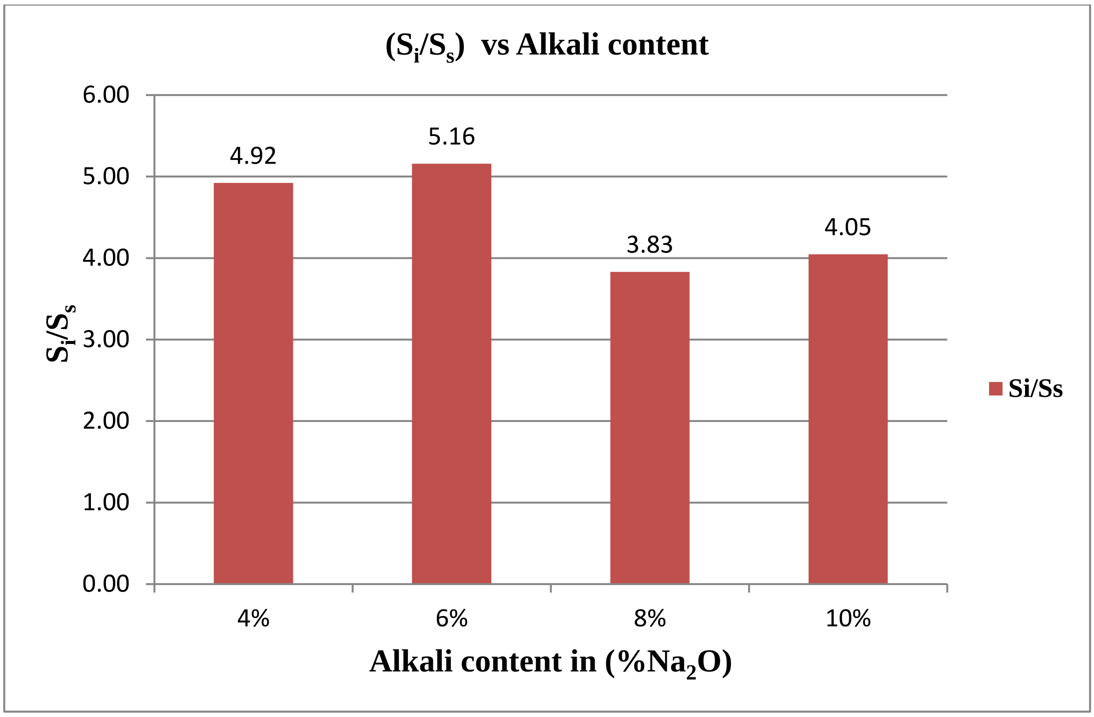


Figure 4.2.2.4

Effect of Na_2O content on Water Sorptivity ratio of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.35

4.2.3 Compressive Strength

4.2.3.1 Effect of Na_2O content

The values of Compressive strength are presented in the table below. It is observed from table and the graphical representation shown below that Compressive strength increases with increase in alkali content. It is observed that with increase in OH^- concentration of the alkali activator solution, the Compressive strength increases because the anion group [OH^-] react with the Ca^{2+} ions present in GGBFS to produce Ca-compounds which serve as the main binder material.

Thus with increase in OH^- concentration that is with increase in alkali (NaOH) concentration , increased amount of Ca-compound which is nothing but calcium silicate hydrate are generated as reaction products , thus increasing the quantity of cementations material, which finally causes increase in strength.

Thus when alkali (NaOH) content increases from 4% to 10% the Compressive strength increases from 44.50 MPA to 71.00 MPA at Water/GGBFS is 0.35 for 7 days and from 48.50 MPA to 80.00 MPA for 28 days and Compressive strength also increases from 45.60 MPA to 82.50 MPA at Water/GGBFS is 0.30 for 7 days and from 68.20 MPA to 90.00 MPA for 28 days respectively.

Table 4.2.3.1 – Effect of Na_2O content on Compressive strength of unexposed Alkali Activated GGBFS paste with Water / GGBS = 0.35

SL. NO.	MIX. I.D.	% Na_2O	Water / GGBS = 0.35	
			Compressive Strength in N/mm^2	
			7 Days	28 Days
1	BFS4-0.8	4%	44.50	48.50
2	BFS6-0.8	6%	55.20	60.00
3	BFS8-0.8	8%	58.67	65.00
4	BFS10-0.8	10%	71.00	80.00

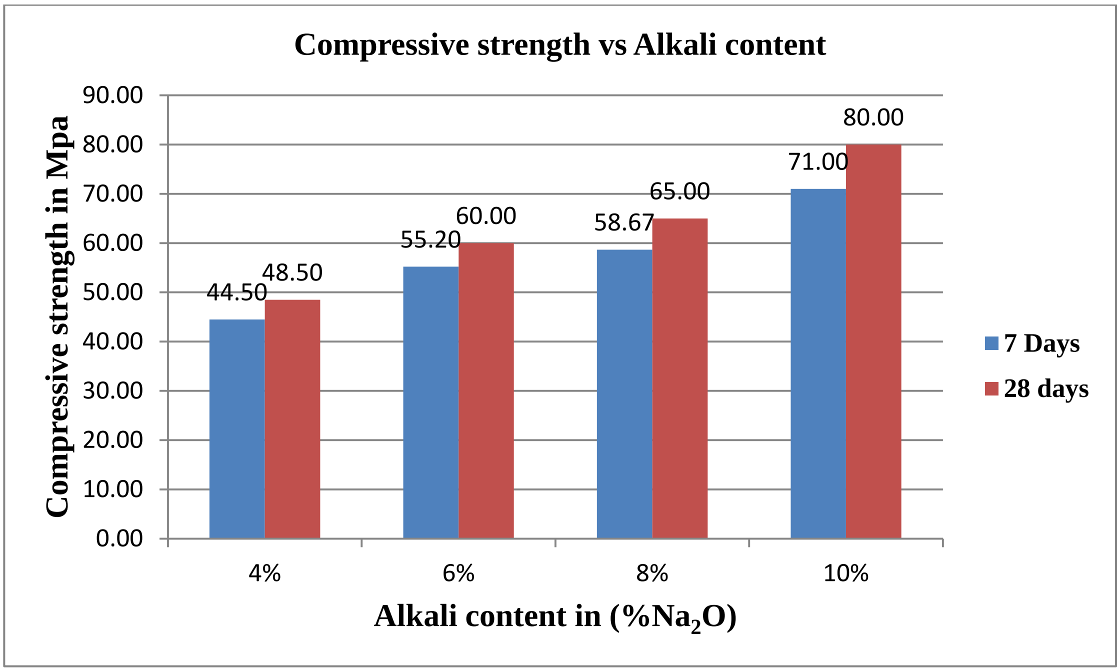


Figure 4.2.3.1

Effect of Na_2O content on Compressive strength of unexposed Alkali Activated GGBFS paste with Water / GGBS = 0.35

Table 4.2.3.1.1 – Effect of Na_2O content on Compressive strength of unexposed Alkali Activated GGBFS paste with Water / GGBS = 0.30

SL. NO.	MIX. I.D.	% Na_2O	Water / GGBS = 0.30	
			Compressive Strength in N/mm^2	
			7 Days	28 Days
1	BFS4-0.8	4%	45.60	68.20
2	BFS6-1.2	6%	70.80	76.40
3	BFS8-1.2	8%	75.20	86.00
4	BFS10-1.0	10%	82.50	90.00

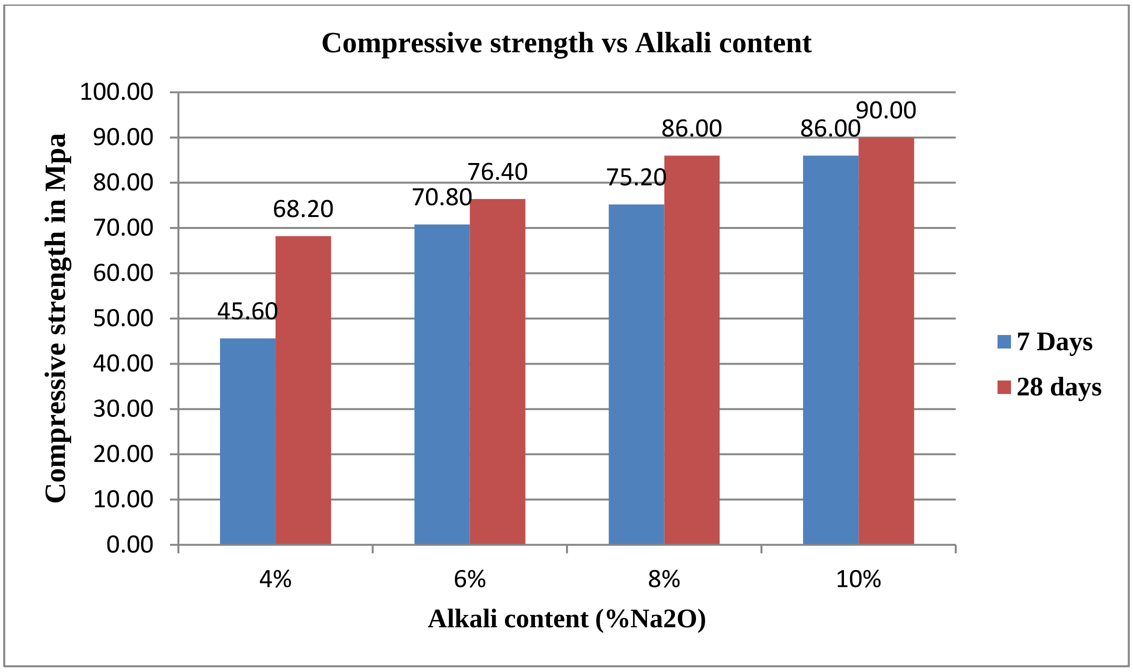


Figure 4.2.3.1.1

Effect of Na_2O content on Compressive strength of unexposed Alkali Activated GGBFS pastes with Water / GGBS = 0.30

4.2.3.2 Effect of SiO_2 content

It is observed from figure that the Compressive strength maximum of 80.00 Mpa for silicate ratio (SiO_2/Na_2O) is 0.8 at water/GGBFS= 0.35 and 90.00 Mpa for silicate ratio (SiO_2/Na_2O) is 1.0 at water/GGBFS= 0.30. Increasing silicate ratio means increasing the concentration of anions of sodium silicate. The anion in sodium silicate reacts with Ca^{2+} dissolving from the surface of the slag grains and forms the primary C-S-H [27]. The C-S-H deposits among the slag grains and makes the paste set quickly and gives higher strength due to dense structure. The higher the silicate content, the more the contribution from silica gel and the higher the strength within a certain range [7]. The degree of reaction increases with the silicate content [8]. The optimum value of silicate ratio is found to be 0.8 corresponding the highest strength, thereafter with an increase in silicate ratio, there is a slight reduction in strength corresponding to peak strength value, which indicates excess silicate contents hinders alkali activation of slag and structure formation.

Table 4.2.3.2.1- Effect of Silicate ratio (SiO_2/Na_2O) on Compressive strength of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.35 and 0.30.

SiO_2 / Na_2O	Water / GGBS = 0.35		Water / GGBS = 0.30	
	Compressive Strength in N/mm^2		Compressive Strength in N/mm^2	
	7 Days	28 Days	7 Days	28 Days
0.8	41.80	45.20	41.20	52.40
1	44.50	48.50	45.60	68.20
1.2	40.10	41.00	38.10	47.50
0.8	55.20	60.00	55.00	72.20
1	57.73	59.07	68.40	70.00
1.2	54.00	56.10	70.80	76.40
0.8	52.00	53.20	55.60	70.50
1	58.67	65.00	61.30	82.50
1.2	32.20	42.40	75.20	86.00
0.8	71.00	80.00	57.50	65.60
1	35.00	43.60	86.00	90.00
1.2	47.40	64.80		

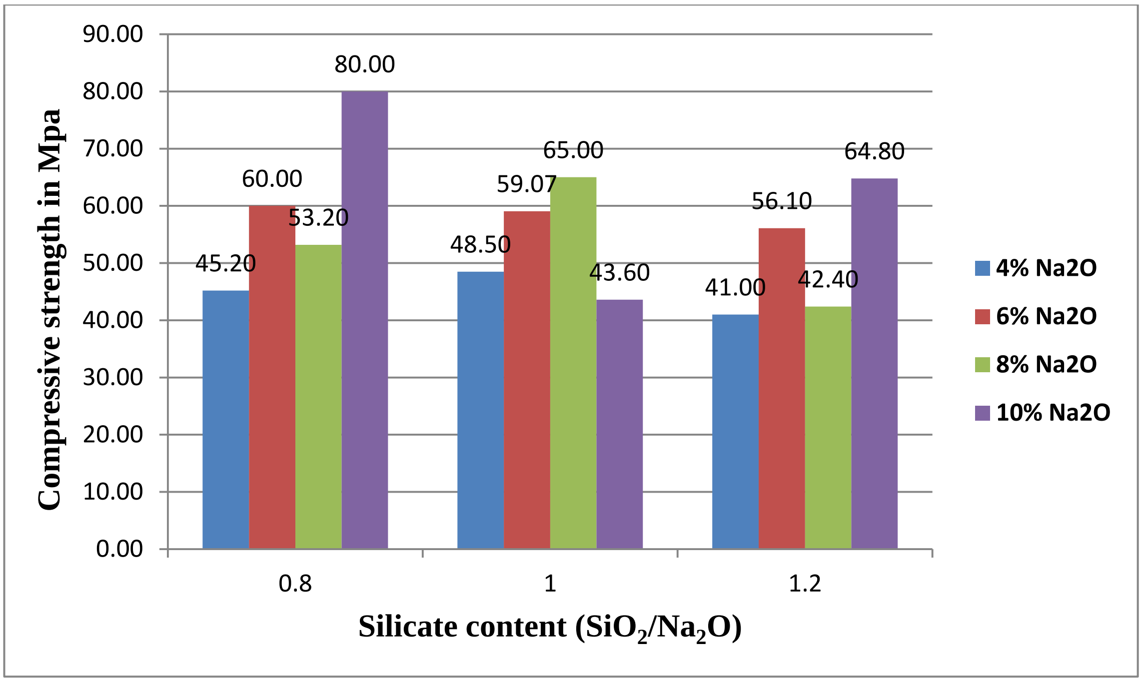


Figure 4.2.3.2.1

Effect of Silicate ratio (SiO_2/Na_2O) on Compressive strength of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.35.

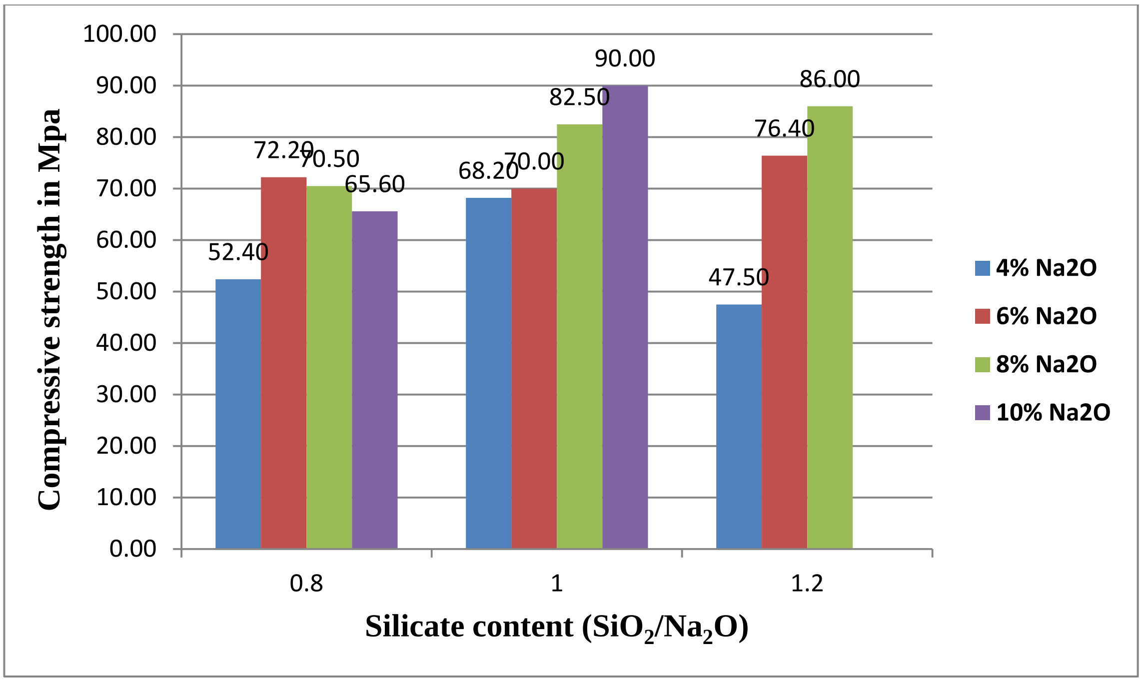


Figure 4.2.3.2.2

Effect of Silicate ratio (SiO_2/Na_2O) on Compressive strength of unexposed Alkali Activated GGBFS paste with Water/GGBFS = 0.30.

4.2.4 Water Absorption

4.2.4.1 Effect of Na_2O content

The values of Water absorption are presented in table below. It is observed from table and graphical representation shown below that water absorption decreases with increase in alkali (NaOH) content. With increase in OH^- more Ca^{2+} ions present in GGBFS the rate of reaction of the anions to form calcium silicate hydrate (C-S-H) gel also increases. With the increased amount of formation of C-S-H cementations binder the porosity of the Alkali Activated GGBFS paste also decreases, which finally hinders the water absorption causing a decrease in water absorption upto 10% at Water/GGBFS is 0.35 and at Water/GGBFS is 0.30 decrease in apparent porosity upto 8%.

Thus Water absorption decreases from 0.1070 to 0.0288 with increase in alkali (NaOH) content from 4% to 10% respectively at Water/GGBFS = 0.35. Similarly water absorption decreases from 0.03029 to 0.0190 with increase in alkali (NaOH) content from 4% to 8% respectively at Water/GGBFS = 0.30.

Table 4.2.4.1.1 – Effect of Na_2O content on Water absorption of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.35

MIX. I.D.	% Na_2O	Water / GGBS = 0.35			
		Dry Weight	Weight in SSD condition	Increase in mass	Increase in mass as a % of dry mass
		in gm.	in gm.	in gm.	in %
BFS4-0.8	4%	204.77	226.68	21.91	10.70%
BFS6-0.8	6%	225.36	235.39	10.03	4.45%
BFS8-0.8	8%	226.26	233.99	7.73	3.42%
BFS10-0.8	10%	240.63	247.55	6.92	2.88%

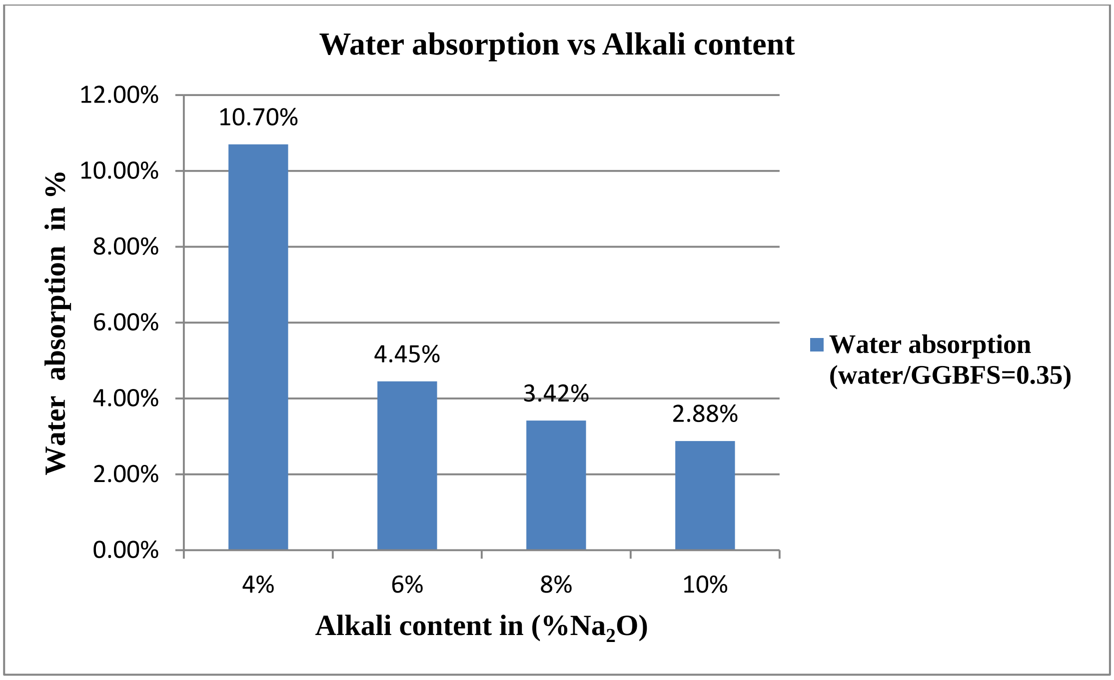


Figure 4.2.4.1.1

Effect of Na_2O content on Water absorption of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.35

Table 4.2.4.1.2 – Effect of Na_2O content on Water absorption of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

MIX. I.D.	% Na_2O	Water / GGBS = 0.30			
		Dry Weight	Weight in SSD condition	Increase in mass	Increase in mass as a % of dry mass
		in gm.	in gm.	in gm.	in %
BFS4-1.2	4%	236.69	243.86	7.17	3.03%
BFS6-0.8	6%	234.62	243.23	8.61	2.10%
BFS8-1.0	8%	238.50	244.70	6.20	1.90%

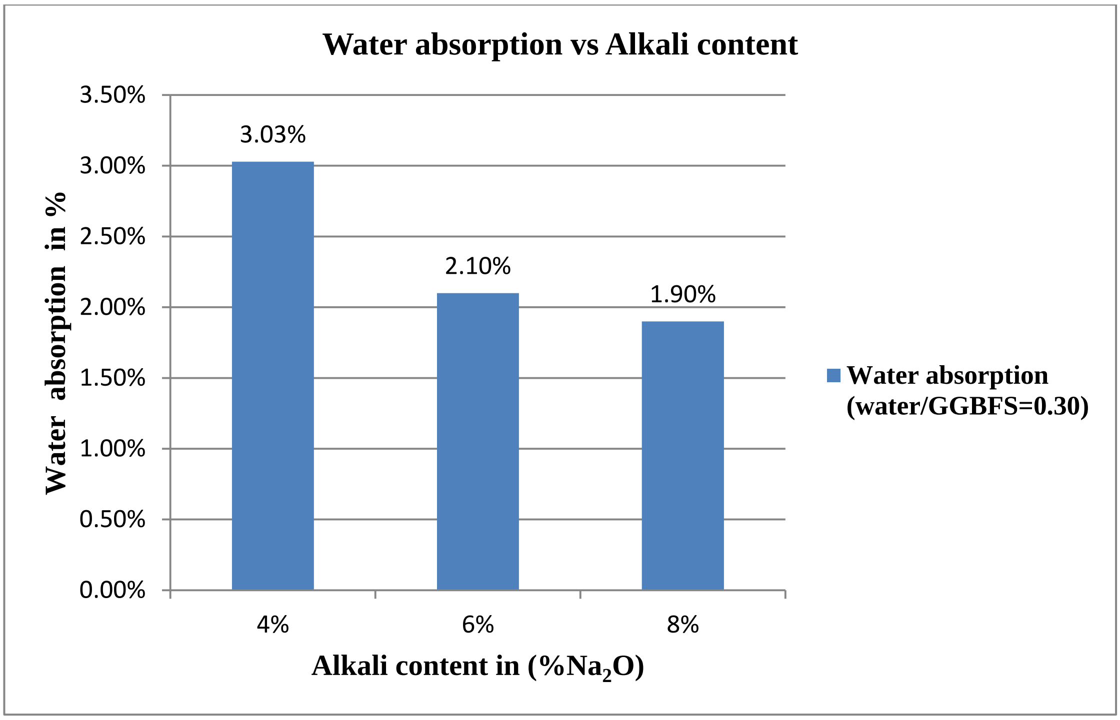


Figure 4.2.4.1.2

Effect of Na_2O content on Water absorption of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

4.2.5 Apparent Porosity

4.2.5.1 Effect of Na_2O content

The values of Apparent porosity are presented in table below. It is observed from table and graphical representation shown below that apparent porosity decreases with increase in alkali (NaOH) content. With increase in OH^- more Ca^{2+} ions present in GGBFS the rate of reaction of the anions to form calcium silicate hydrate (C-S-H) gel also increases. With the increased amount of formation of C-S-H cementations binder the porosity of the Alkali Activated GGBFS pastes also decreases, thus improving the pore structure of Alkali Activated GGBFS pastes ,which finally causing a decrease in apparent porosity upto 10% at Water/GGBFS is 0.35 and at water/GGBFS is 0.30 decrease in apparent porosity upto 8%.

Thus apparent porosity decreases from 0.1858 to 0.0569 with increase in alkali (NaOH) content from 4% to 10% respectively at Water/GGBFS = 0.35. Similarly apparent porosity decreases from 0.0584 to 0.0320 with increase in alkali (NaOH) content from 4% to 8% respectively at Water/GGBFS = 0.30.

Table 4.2.5.1.1– Effect of Na_2O content on Apparent porosity of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.35

MIX. I.D.	% Na_2O	Water / GGBS = 0.35			
		Dry Weight (W_d)	Weight in SSD condition (W_s)	Submerged weight (W_i)	Aparent Porosity $=((W_s-W_d)/(W_s-W_i))x100$
		in gm.	in gm.	in gm.	in %
BFS4-0.8	4%	204.77	226.68	108.75	18.58%
BFS6-0.8	6%	225.36	235.39	114.82	8.32%
BFS8-0.8	8%	226.26	233.99	125.17	7.10%
BFS10-0.8	10%	240.63	247.55	125.91	5.69%

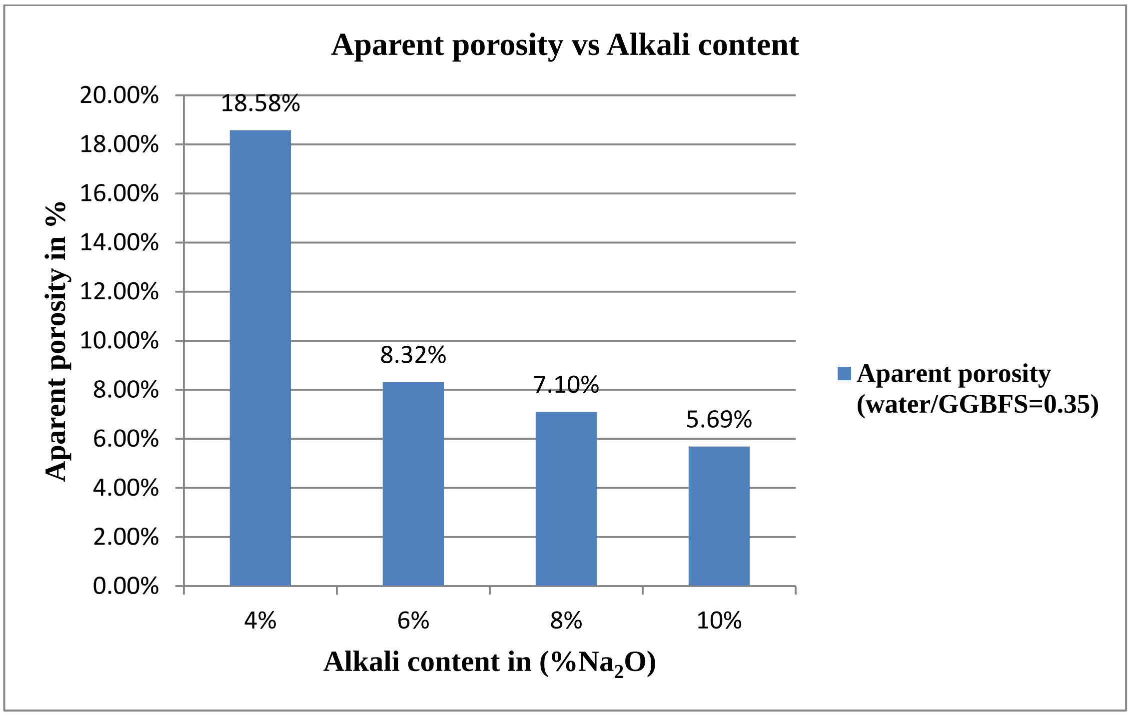


Figure 4.2.5.1.1

Effect of Na_2O content on Apparent porosity of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.35

Table 4.2.5.1.2– Effect of Na_2O content on Apparent porosity of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

MIX. I.D.	% Na_2O	Water / GGBS = 0.30			
		Dry Weight (W_d)	Weight in SSD condition (W_s)	Submerged weight (W_i)	Aparent Porosity =((W_s-W_d)/(W_s-W_i))x100
		in gm.	in gm.	in gm.	in %
BFS4-1.2	4%	236.69	243.86	121.15	5.84%
BFS6-0.8	6%	234.62	243.23	121.50	3.74%
BFS8-1.0	8%	238.50	244.70	121.97	3.20%

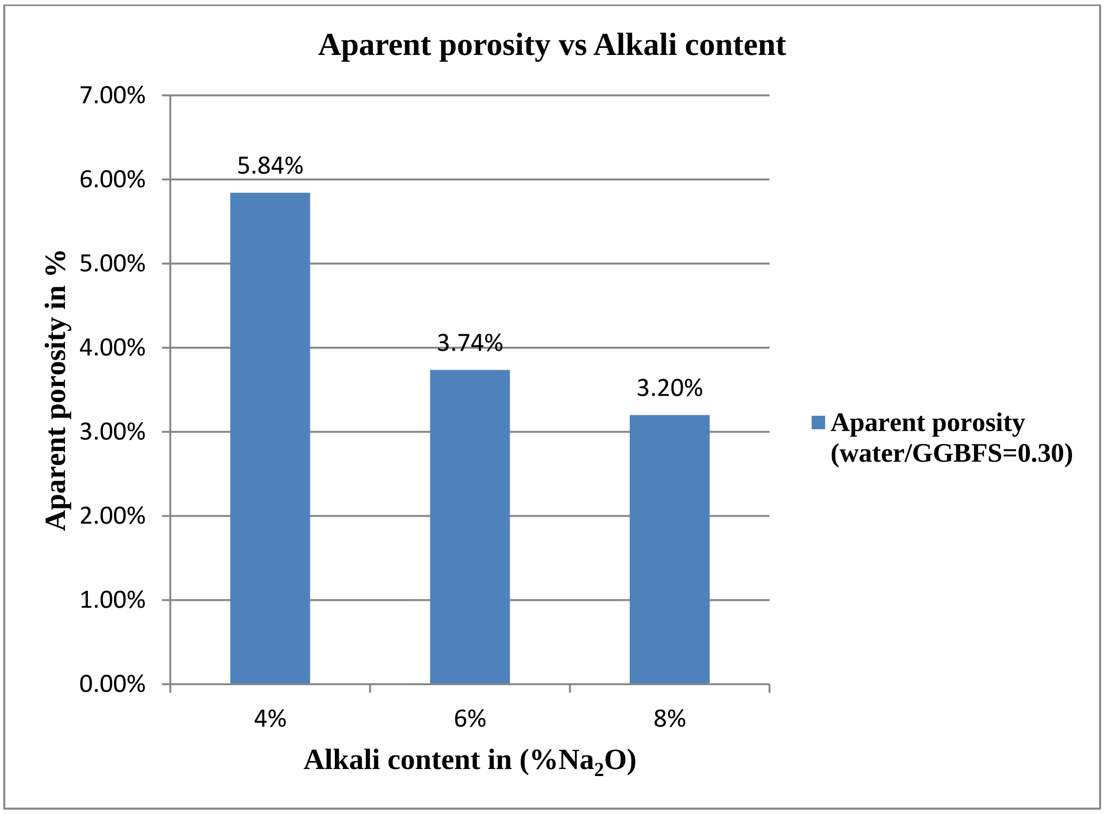


Figure 4.2.5.1.2

Effect of Na_2O content on Apparent porosity of unexposed Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

4.3. AAGGBFS test specimens Exposed to Sulphuric Acid

4.3.1. Compressive Strength changes in Sulphuric Acid solution

4.3.1.1. Percentage change in Compressive strength vs. Concentration

The effect of % change in Compressive Strength for paste specimens which are exposed to sulphuric acid solution are shown in figures below. After 28 days of water curing the alkali activated GGBFS pastes are exposed to sulphuric acid solution for 7 days, 14 days and 21 days respectively.

The main reaction products which are formed when alkali activated GGBFS pastes are exposed to sulphuric acid solution are sodium sulphate formed by replacement of unreacted alkali (NaOH) and ettringite [$Ca_2Al_2(SO_4)_3(OH)_{12}.26H_2O$] formed when SO_4^{2-} ions react with C-S-H gel of alkali activated GGBFS pastes. Both these reaction products are not cementations. Thus with increase in duration of exposure and concentration of sulphuric acid solution the quantity of non-cementations and non – metallic reaction products also increases which cause a decrease in compressive strength.

So, % decrease of Compressive strength increases with both exposure duration and concentration of sulphuric acid at water/GGBFS is 0.35 and 0.30.

Table – 4.3.1.1.1 Effect of Concentration of Sulphuric acid solution on percentage change in Compressive strength of Alkali Activated GGBFS pastes at Water/GGBFS = 0.35

SL. NO.	MIX. I.D.	% Na_2O	Water / GGBFS = 0.35		
			Exposure duration	Concentration of sulphuric acid	Percentage change in compressive strength
1	BFS10-0.8	10	7 Days	2%	-15.00
				4%	-48.00
				6%	-54.00
			14 Days	2%	-40.00
				4%	-59.30
				6%	-67.95
			21 Days	2%	-50.00
				4%	-81.00
				6%	-82.00

Table – 4.3.1.1.2 Effect of Concentration of Sulphuric acid solution on percentage change in Compressive strength of Alkali Activated GGBFS pastes at Water/GGBFS = 0.30

SL. NO.	MIX. I.D.	% Na_2O	Water / GGBFS = 0.30		
			Exposure duration	**Concentration of sulphuric acid**	**Percentage change in compressive strength**
1	BFS8-1.2	8	7 Days	2%	-2.3256
				4%	-43.2558
				6%	-62.7907
			14 Days	2%	-30.2326
				4%	-63.7209
				6%	---
			21 Days	2%	-34.8837
				4%	-44.1860
				6%	-62.7907
2	BFS10-1.0	10	7 Days	2%	-6.6667
				4%	-27.5556
				6%	-51.5556
			14 Days	2%	-28.8889
				4%	-48.3333
				6%	---
			21 Days	2%	-11.1111
				4%	-45.7778
				6%	-64.4444

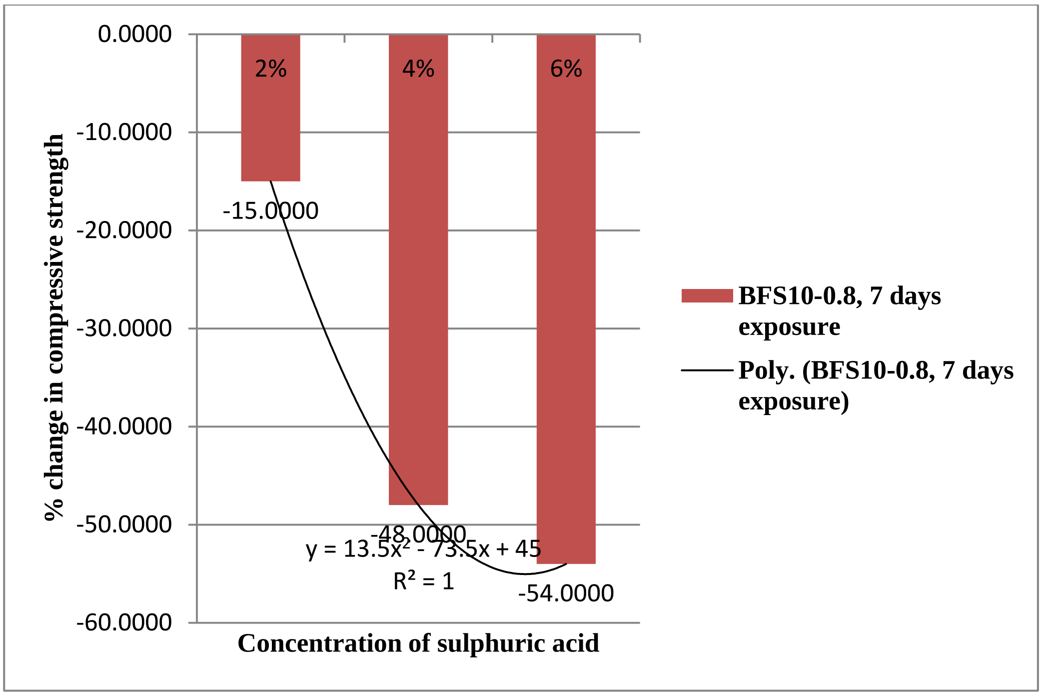


Figure 4.3.1.1.1.1

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 7 days Exposure and Water/GGBFS=0.35

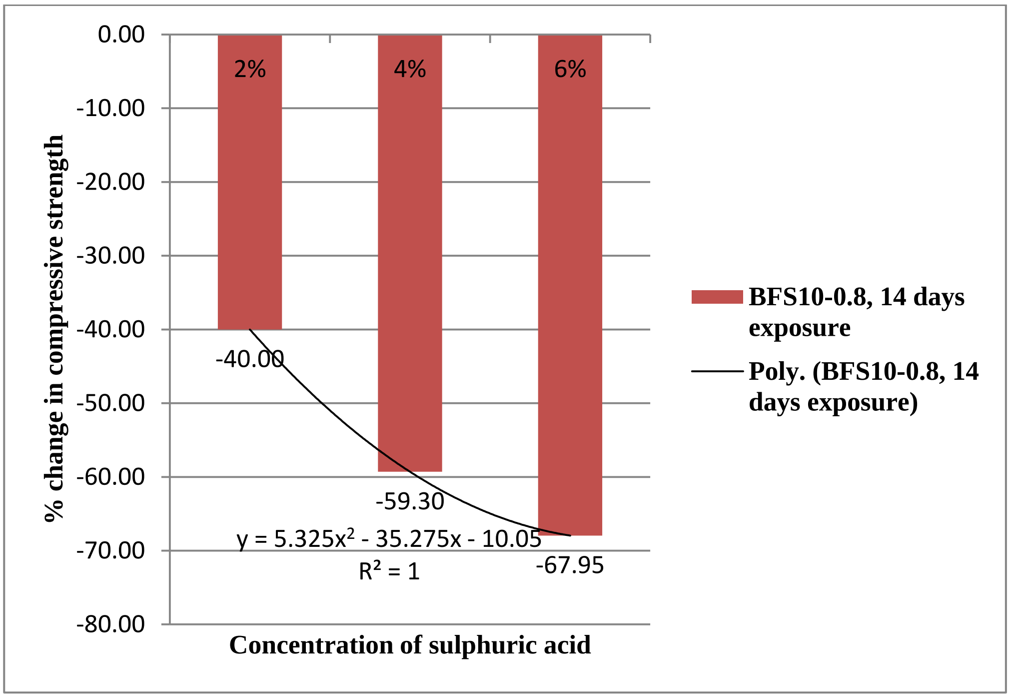


Figure 4.3.1.1.1.2

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 14 days Exposure and Water/GGBFS=0.35

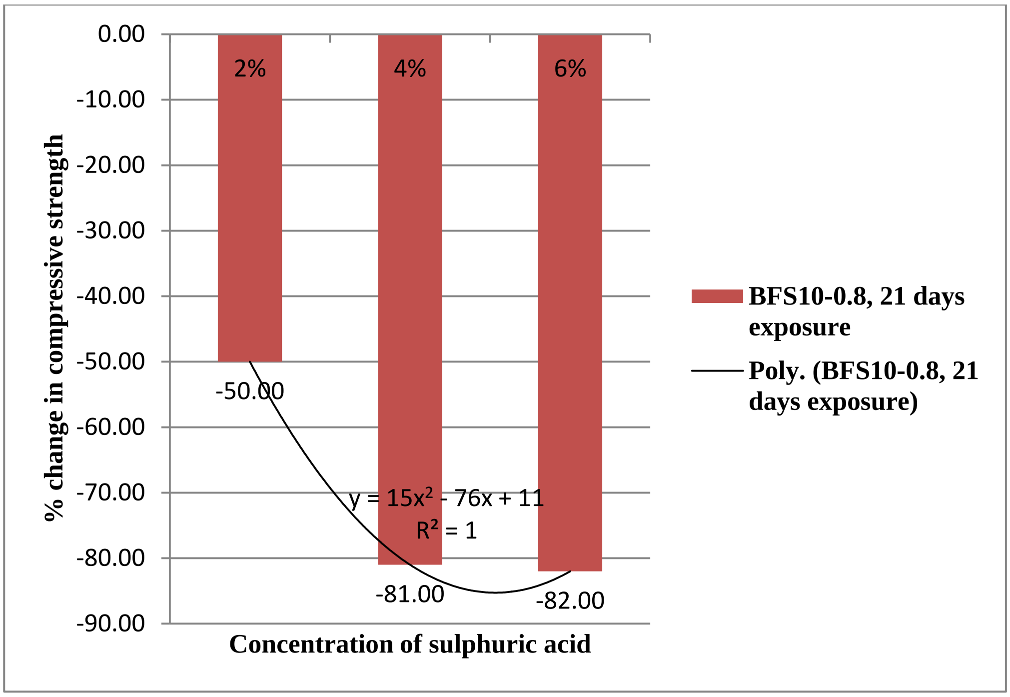


Figure 4.3.1.1.1.3

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 21 days Exposure and Water/GGBFS=0.35

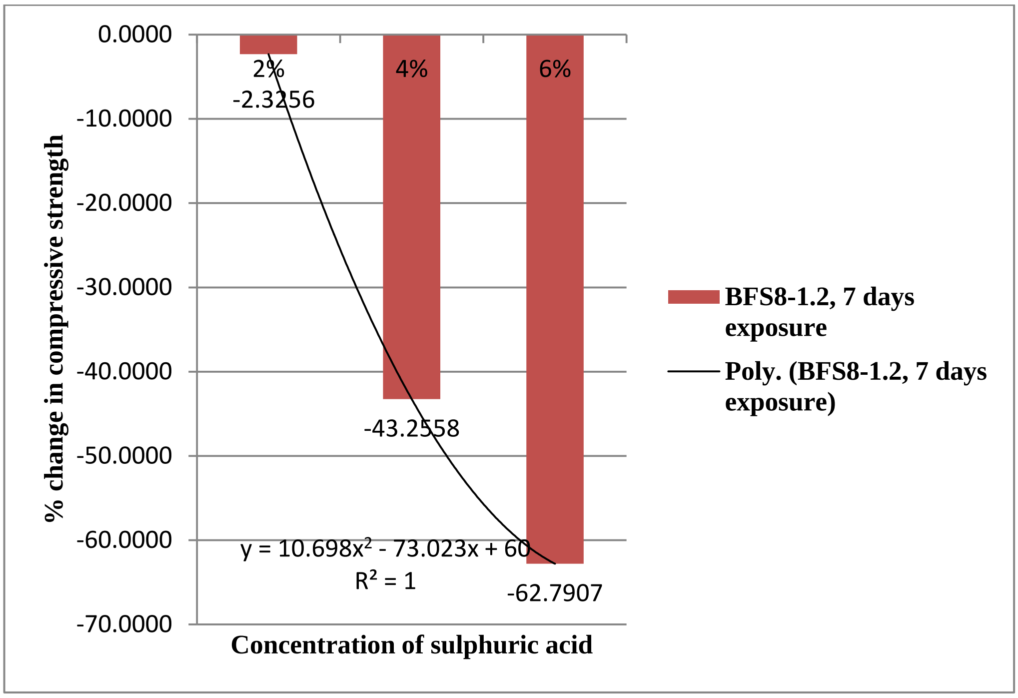


Figure 4.3.1.1.2.1

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 7 days Exposure and Water/GGBFS=0.30

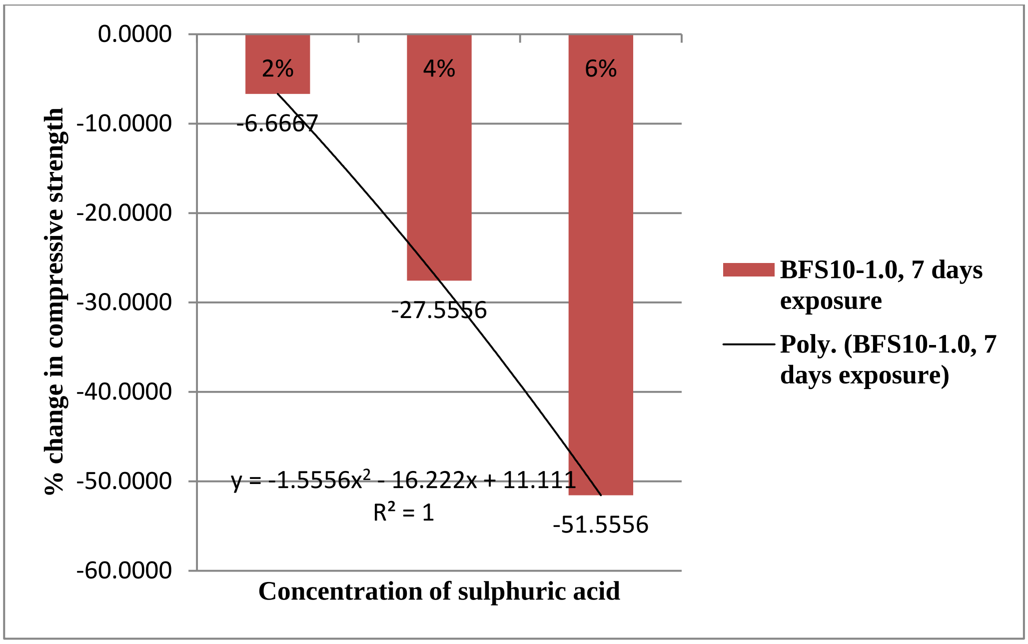


Figure 4.3.1.1.2.2

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 7 days Exposure and Water/GGBFS=0.30

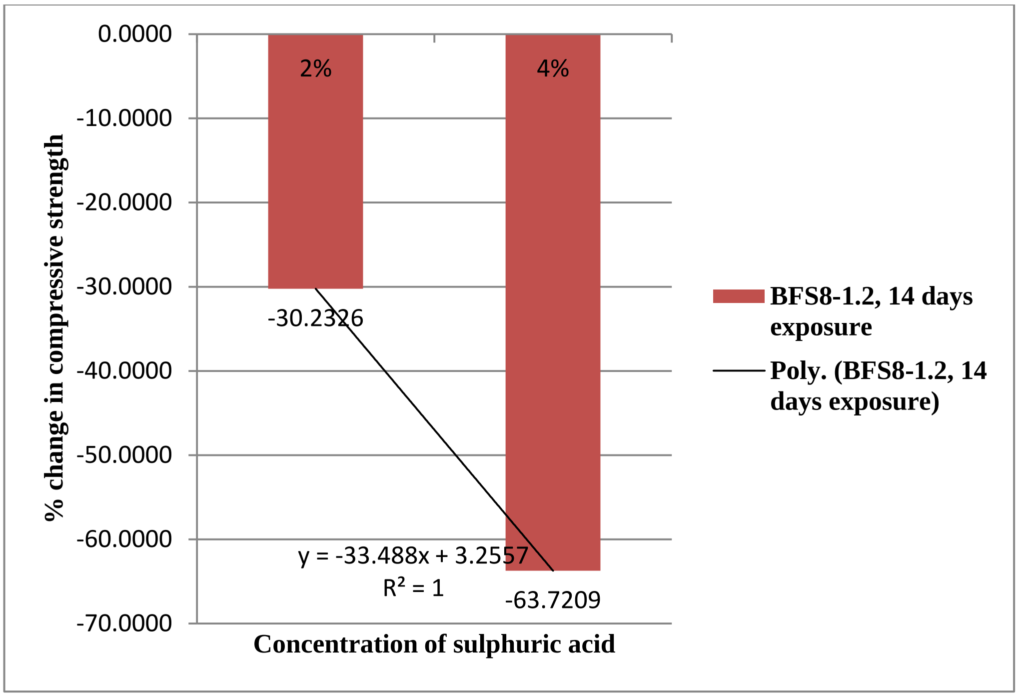


Figure 4.3.1.1.2.3

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 14 days Exposure and Water/GGBFS=0.30

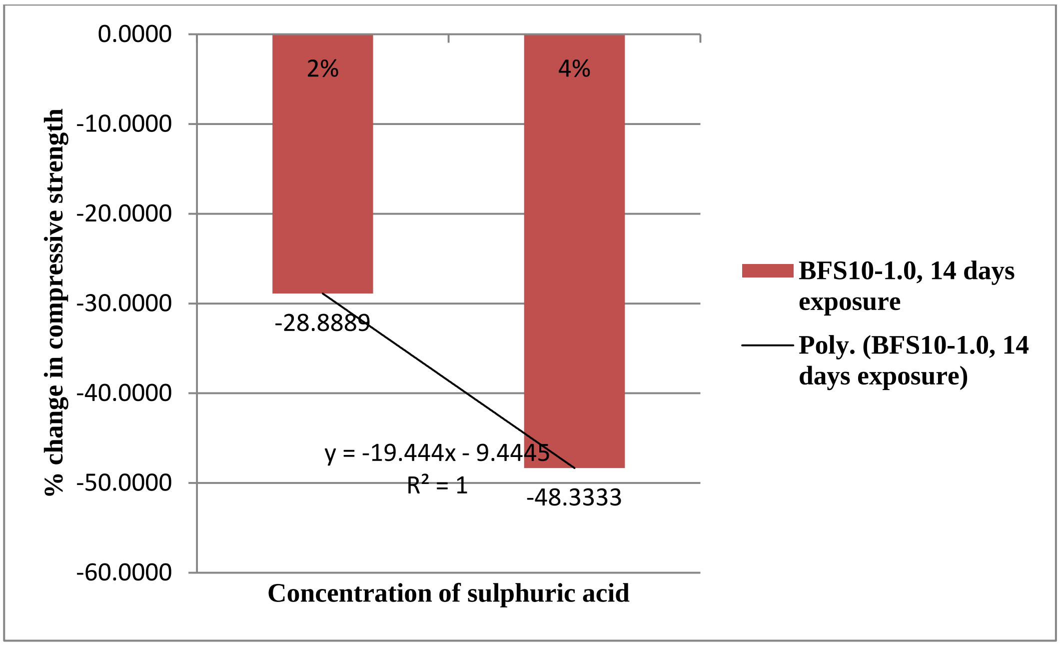


Figure 4.3.1.1.2.4

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 14 days Exposure and Water/GGBFS=0.30

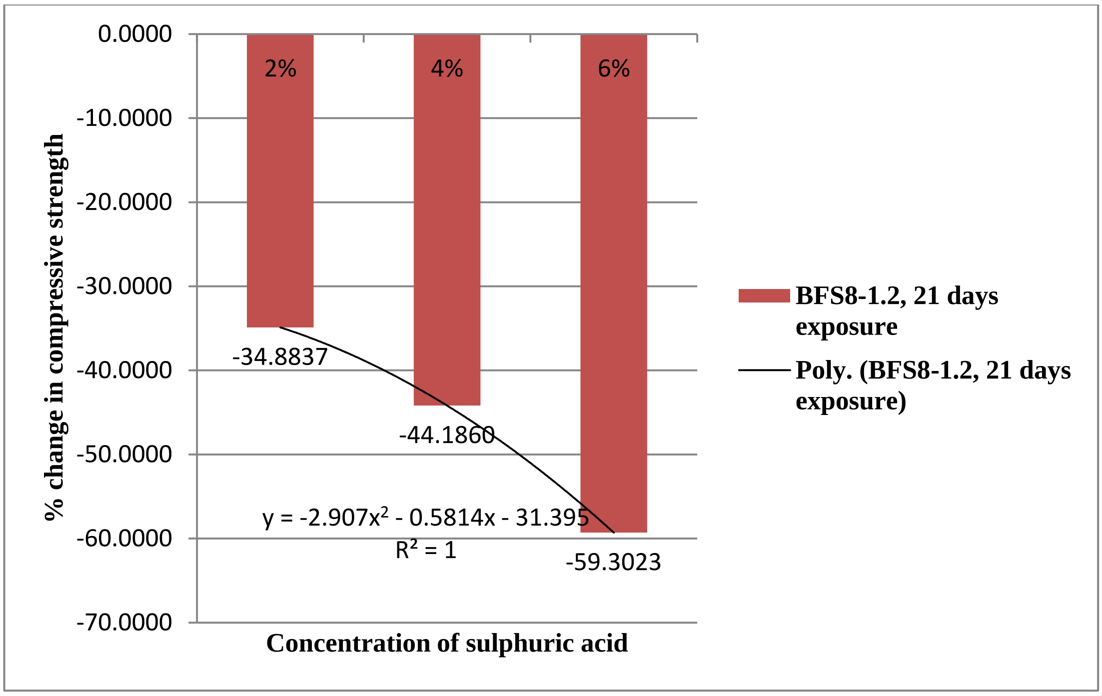


Figure 4.3.1.1.2.5

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 21 days Exposure and Water/GGBFS=0.30

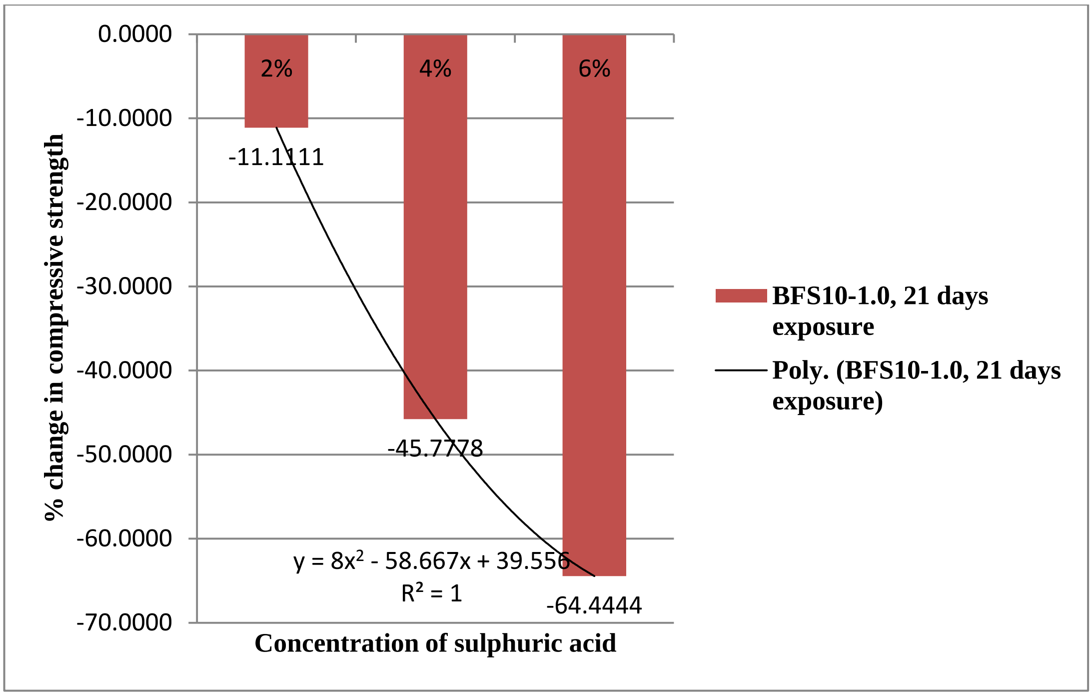


Figure 4.3.1.1.2.6

Effect of Concentration of Sulphuric acid solution on percentage change in Compressive Strength of Alkali Activated GGBFS pastes. - 21 days Exposure and Water/GGBFS=0.30

4.3.1.2. Percentage change in Compressive Strength vs. Duration of Exposure in Sulphuric Acid solution

Table 4.3.1.2.1. - Effect of Duration of Exposure in Sulphuric acid solution on percentage change in Compressive strength for Alkali Activated GGBFS pastes at Water/GGBFS = 0.35

SL. NO.	MIX. I.D.	Water / GGBFS = 0.35		
		Concentration of Sulphuric acid	Exposure duration	Percentage change in Compressive strength
1	BFS10-0.8	2%	7 Days	-15.00
			14 Days	-40.00
			21 Days	-50.00
		4%	7 Days	-48.00
			14 Days	-59.30
			21 Days	-81.00
		6%	7 Days	-54.00
			14 Days	-67.95
			21 Days	-82.00

Table 4.3.1.2.2 - Effect of Duration of Exposure in Sulphuric acid solution on percentage change in Compressive strength for Alkali Activated GGBFS pastes at Water/GGBFS = 0.30

SL. NO.	MIX. I.D.	Water / GGBFS = 0.30		
		Concentration of Sulphuric acid	Exposure duration	Percentage change in Compressive strength
1	BFS8-1.2	2%	7 Days	-2.3256
			14 Days	-30.2326
			21 Days	-34.8837
		4%	7 Days	-43.2558
			14 Days	-63.7209
			21 Days	-44.1860
		6%	7 Days	-62.7907
			14 Days	---
			21 Days	-59.3023
2	BFS10-1.0	2%	7 Days	-6.6667
			14 Days	-28.8889
			21 Days	-11.1111
		4%	7 Days	-27.5556
			14 Days	-48.3333
			21 Days	-45.7778
		6%	7 Days	-51.5556
			14 Days	---
			21 Days	-64.4444

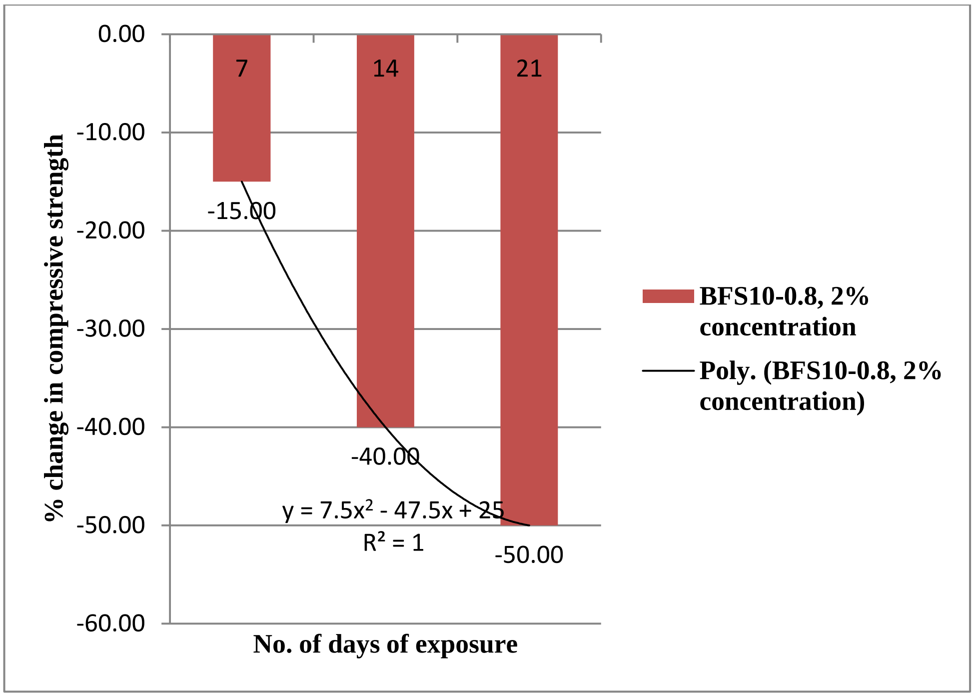


Figure 4.3.1.2.1.1

Effect of Duration of Exposure in Sulphuric acid solution(2% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.35

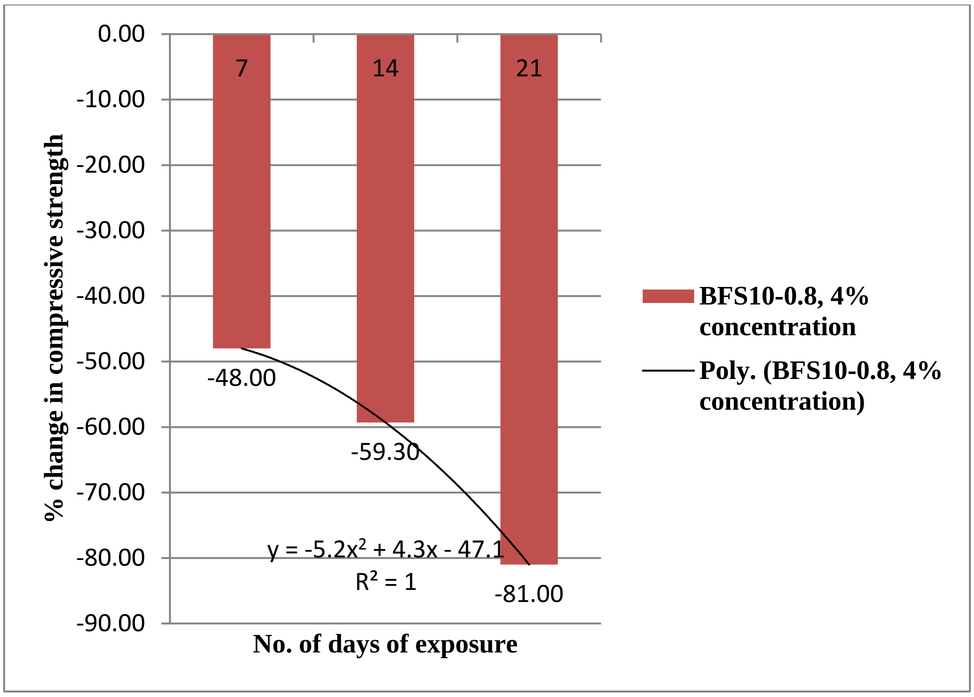


Figure 4.3.1.2.1.2

Effect of Duration of Exposure in Sulphuric acid solution(4% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.35

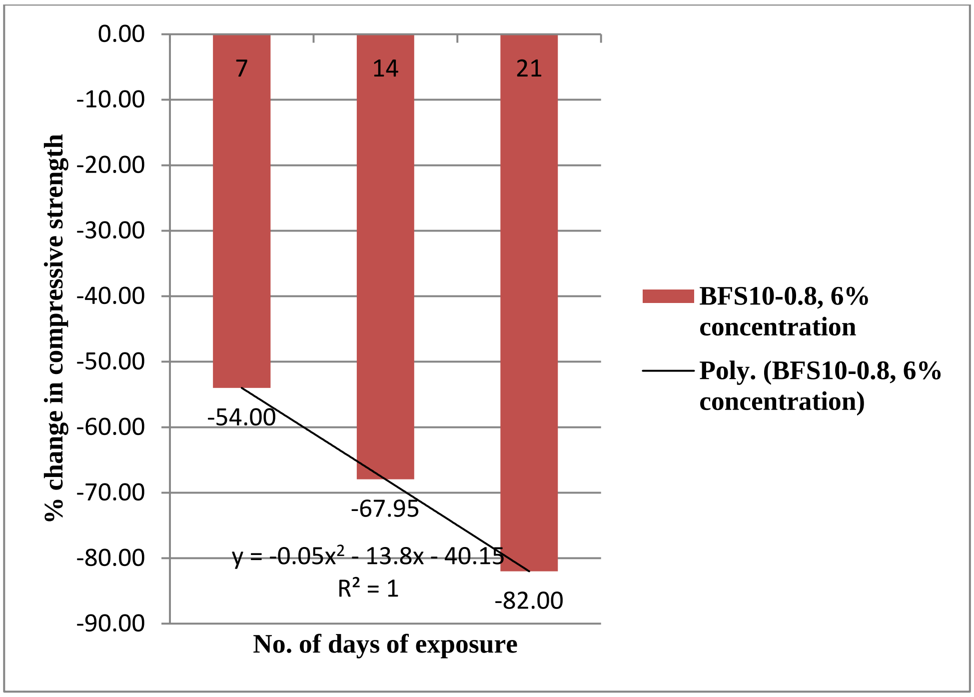


Figure 4.3.1.2.1.3

Effect of Duration of Exposure in Sulphuric acid solution(6% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.35

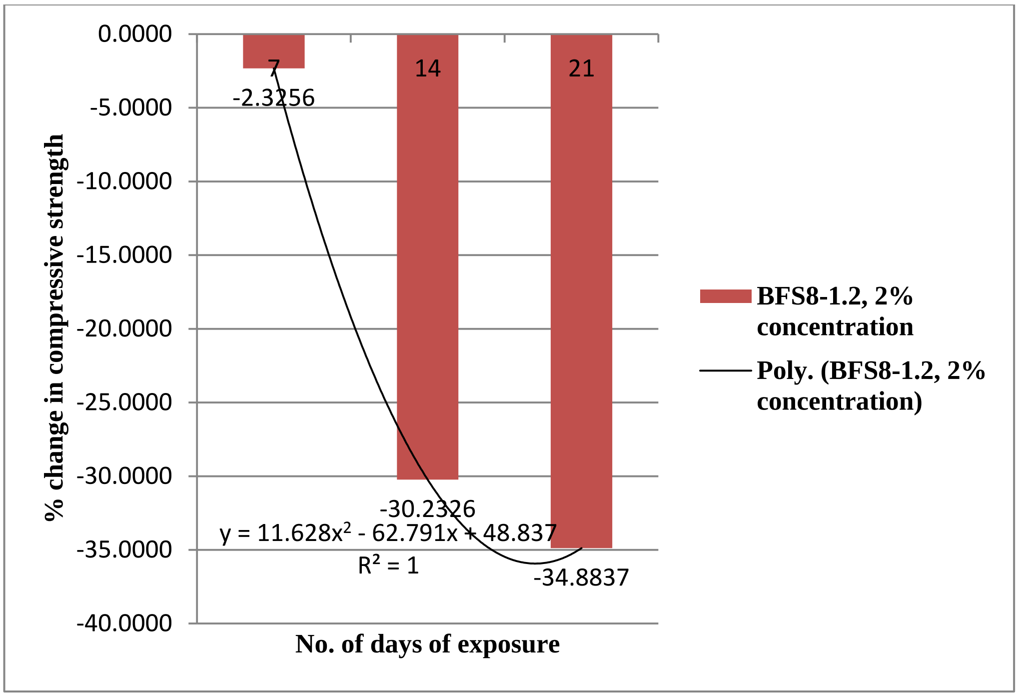


Figure 4.3.1.2.2.1

Effect of Duration of Exposure in Sulphuric acid solution(2% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

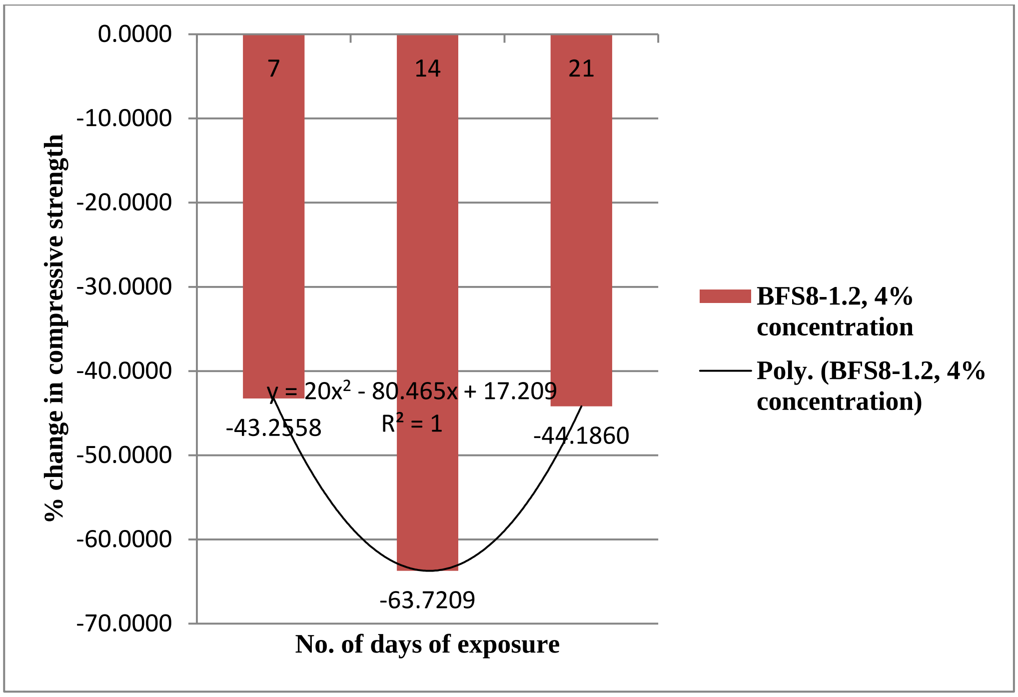


Figure 4.3.1.2.2.2

Effect of Duration of Exposure in Sulphuric acid solution(4% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

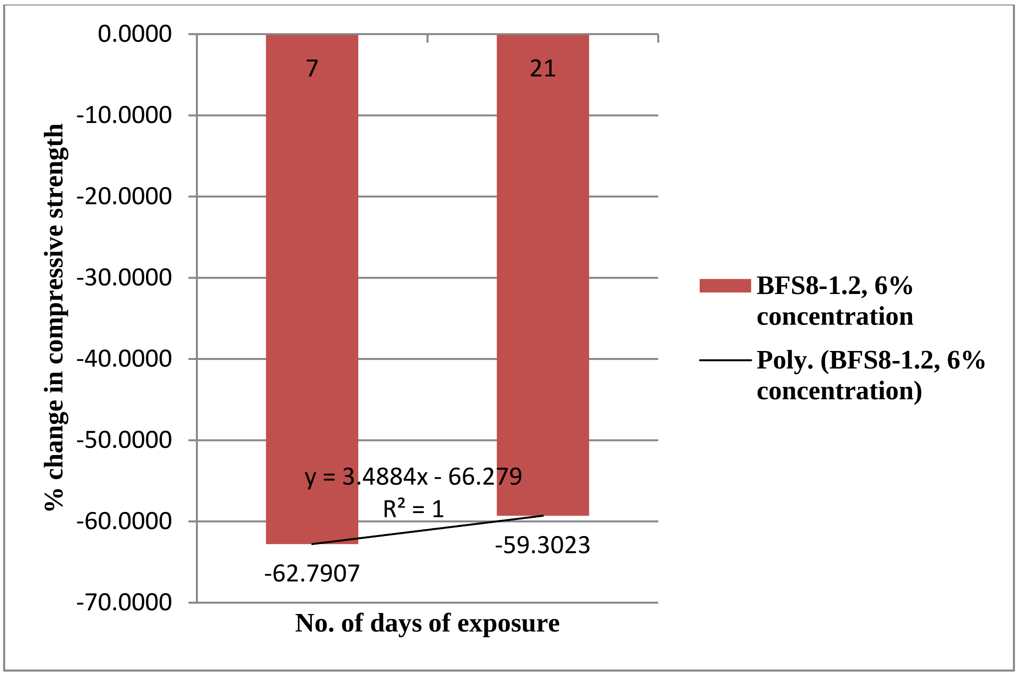


Figure 4.3.1.2.2.3

Effect of Duration of Exposure in Sulphuric acid solution(6% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

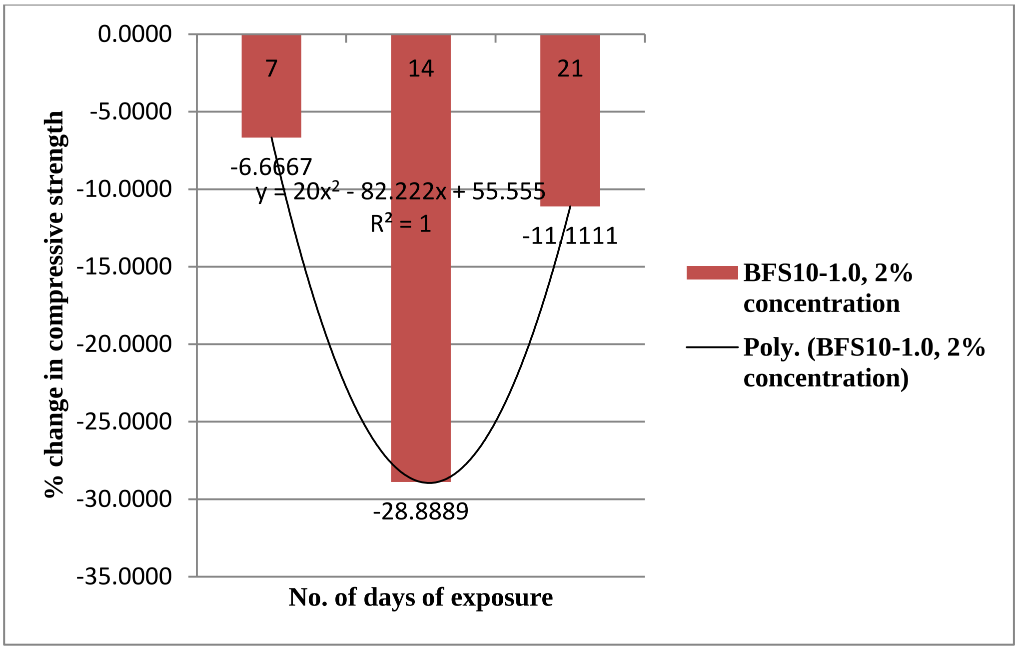


Figure 4.3.1.2.2.4

Effect of Duration of Exposure in Sulphuric acid solution(2% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

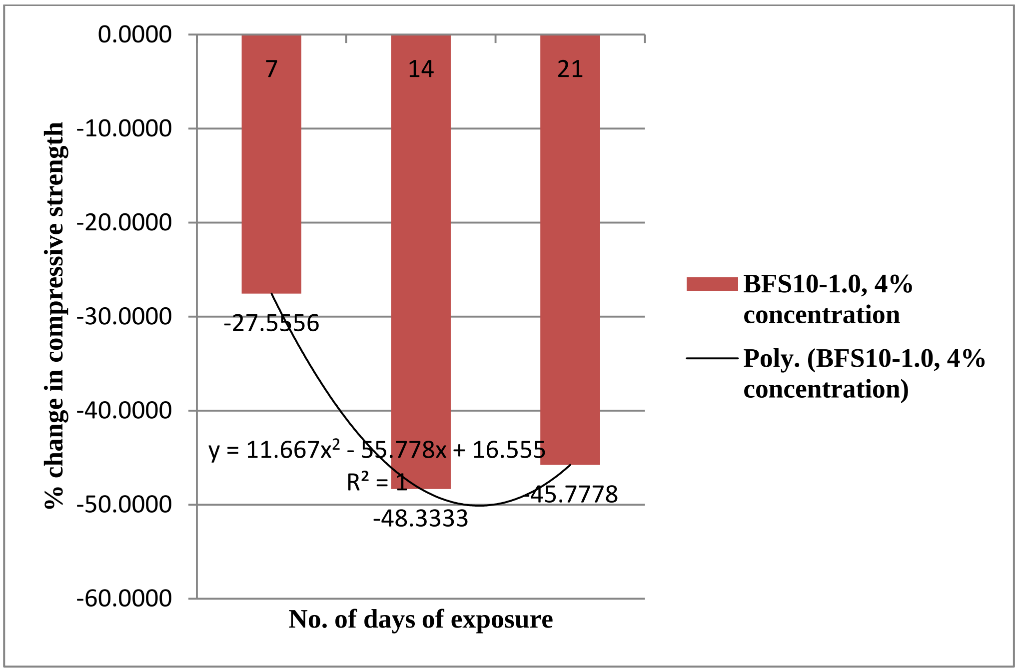


Figure 4.3.1.2.2.5

Effect of Duration of Exposure in Sulphuric acid solution(4% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

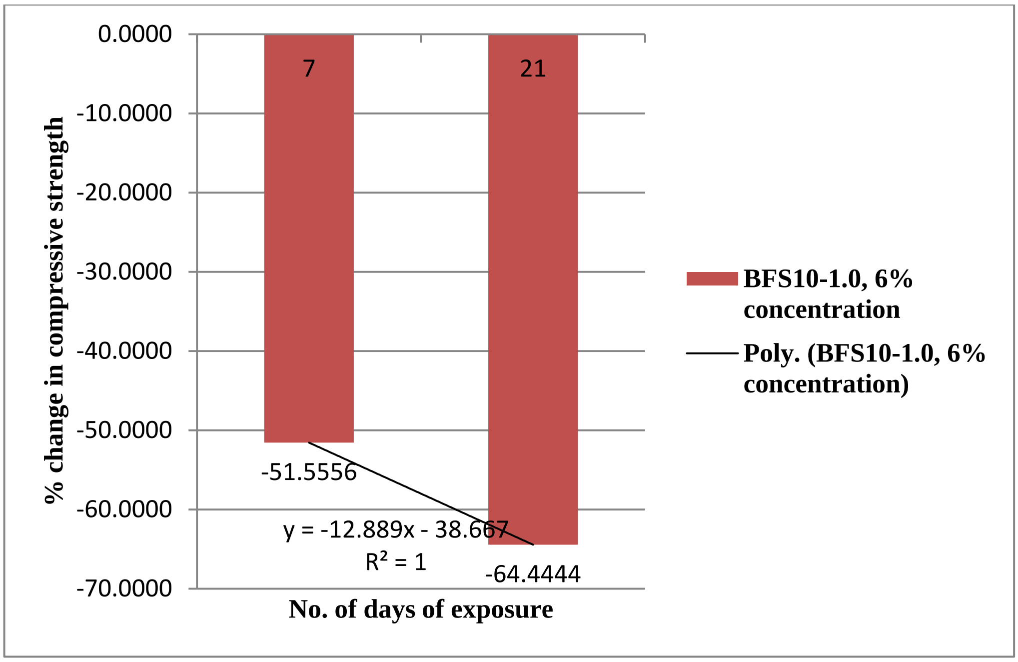


Figure 4.3.1.2.2.6

Effect of Duration of Exposure in Sulphuric acid solution(6% Concentrated) vs. percentage change in Compressive strength for Alkali Activated GGBFS pastes with Water/GGBFS = 0.30

5.0 Micro Structural Study (SEM)

5.1 Unexposed Alkali Activated Specimens

Samples for Scanning Electron Microscope (SEM) is carried out for blast furnace slag and for the Alkali Activated paste specimen with a alkali content 10% and silicate ratio 0.8 at Water/GGBFS is 0.35 and alkali content 8% to 10%, silicate ratio 1.2 to 1.0 at Water/GGBFS is 0.30 shown in figure. SEM images show a highly amorphous microstructure with some crystalline phases. Uniformly distributed wide cracks are found on the surface of the specimens at high alkali content and low Water/GGBFS= 0.30 due to drying shrinkage effect. However, more specific investigation is required to understand the exact effect of drying shrinkage.

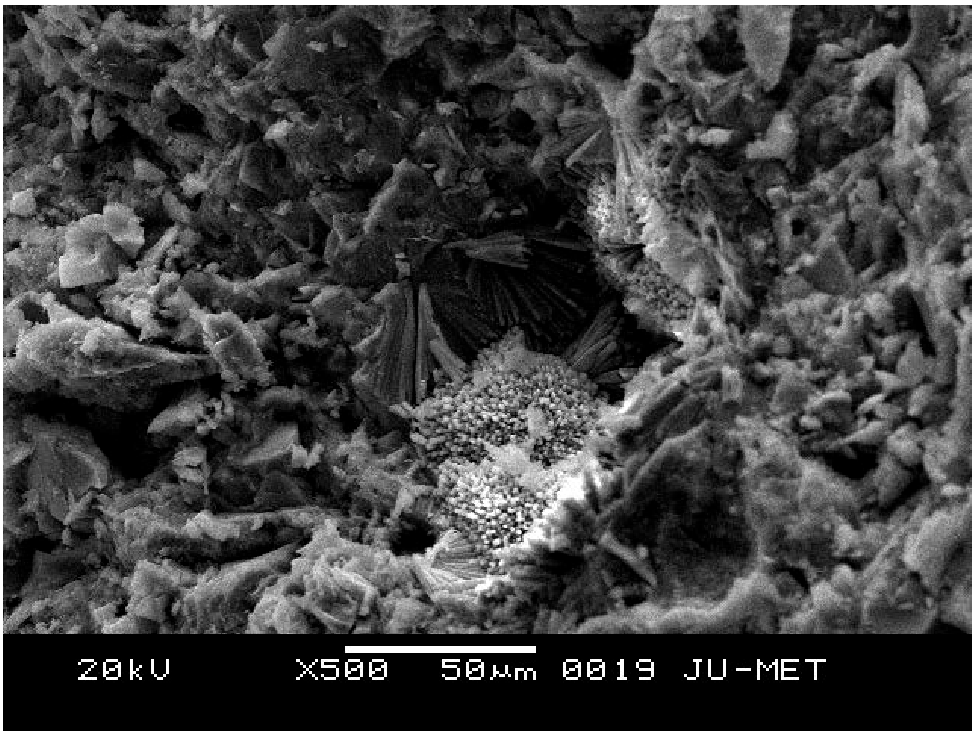


Figure 5.1.1

SEM image (500X) of an Unexposed Alkali Activated GGBFS paste at Water/GGBFS = 0.35

Figure 5.1.2

SEM image (1000X) of an Unexposed Alkali Activated GGBFS paste at Water/GGBFS = 0.35

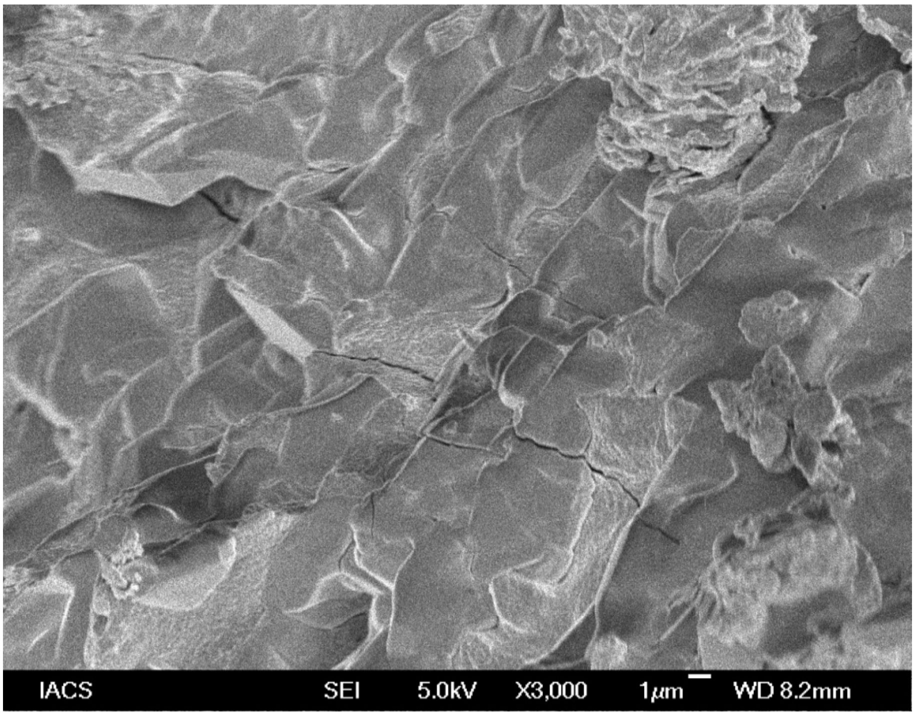


Figure 5.1.3

SEM image (3000X) of an Unexposed Alkali Activated GGBFS paste at Water/GGBFS = 0.30

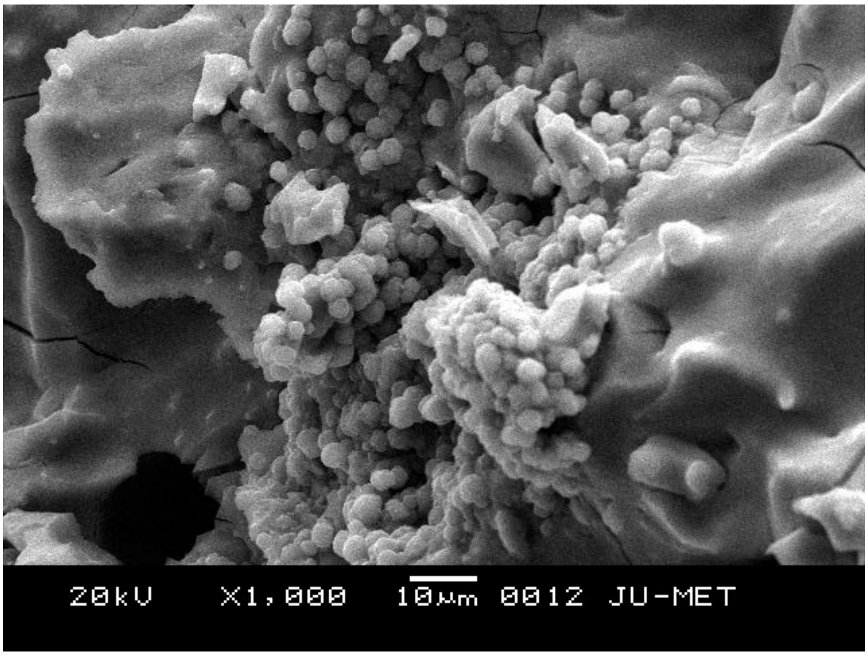


Figure 5.1.4

SEM image (1000X) of an Unexposed Alkali Activated GGBFS paste at Water/GGBFS = 0.30

5.2 Alkali Activated Composites Exposed to Sulphuric Acid Solution

When the Alkali Activated GGBFS pastes are exposed to Sulphuric acid, the unreacted alkali (NaOH) and the binder (C-S-H) react with sulphuric acid to form sodium sulphate (Na_2SO_4) and ettringite $[Ca_6Al_2(SO_4)_3(OH)_{12.}26H_2O]$.

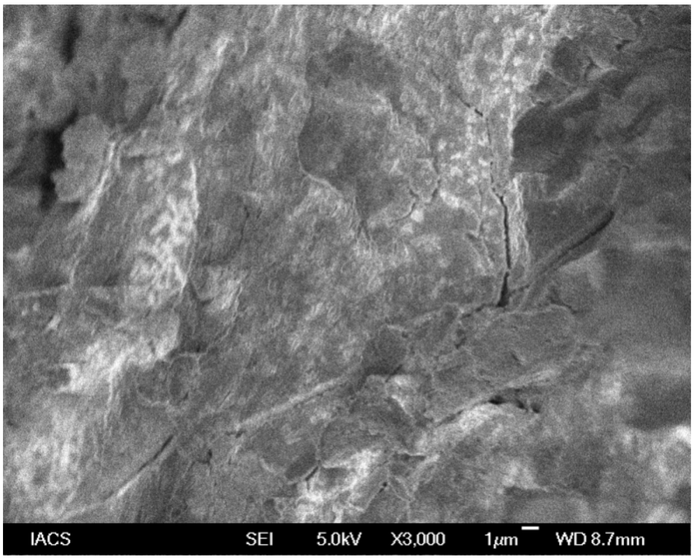


Figure 5.2.1

SEM image (3000X) of Alkali Activated GGBFS paste(7 days Exposer, 2% Concentration of Sulphuric acid solution, Water/GGBFS = 0.30)

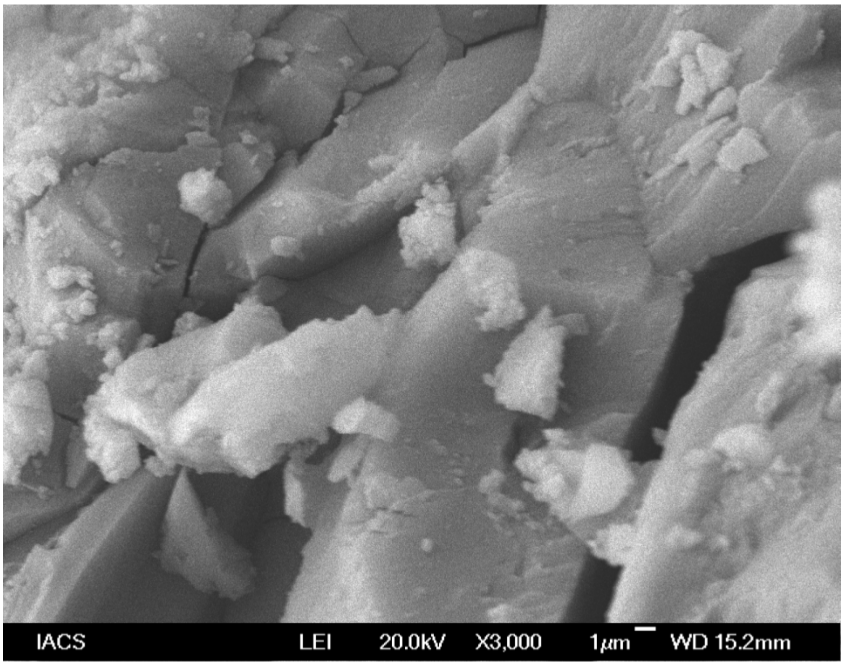


Figure 5.2.2

SEM image (3000X) of Alkali Activated GGBFS paste(7 days Exposer, 2% Concentration of Sulphuric acid solution, Water/GGBFS = 0.30)

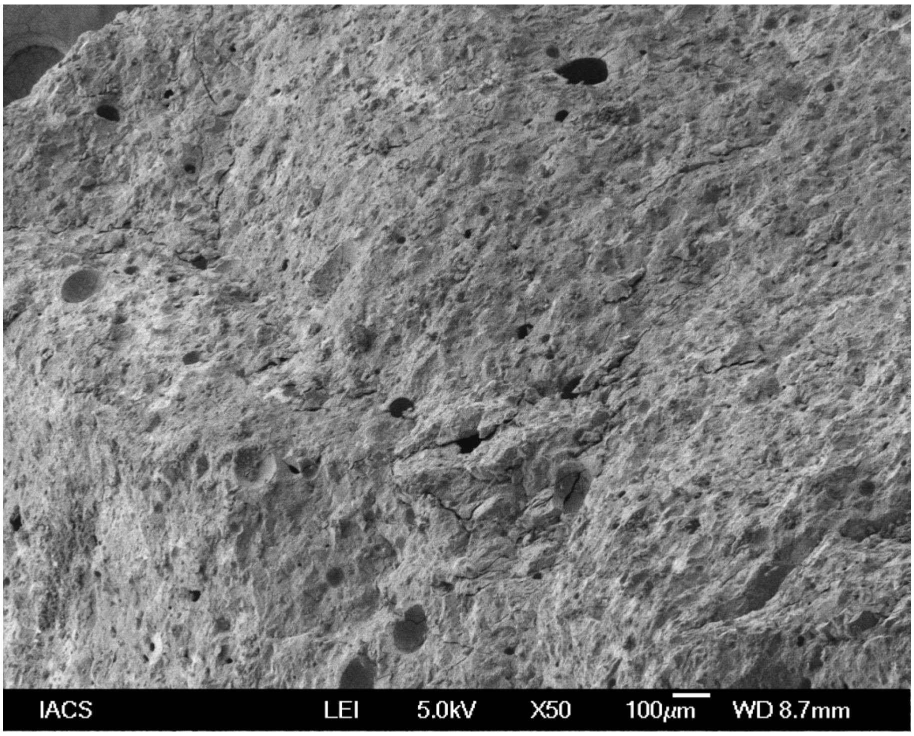


Figure 5.2.3

SEM image (50X) of Alkali Activated GGBFS paste(14 days Exposer, 2% Concentration of Sulphuric acid solution, Water/GGBFS = 0.30)

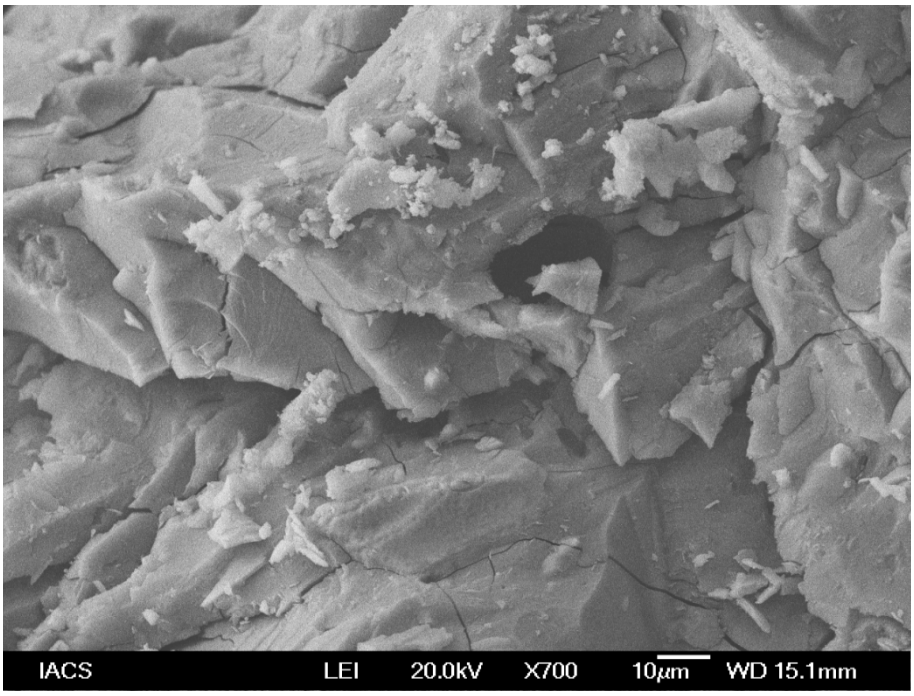


Figure 5.2.4

SEM image (700X) of Alkali Activated GGBFS paste(14 days Exposer, 2% Concentration of Sulphuric acid solution, Water/GGBFS = 0.30)

6.1 Preamble

Present study aimed to appreciate strength and durability related aspects of AAGGBFS pastes. The paste specimens are made keeping alkali content(Na_2O) varied from 8% to 10%, Silicate ratio varied from 0.8 to 1.2 and Water/GGBFS ratio varied from 0.35 to 0.30.

Different properties like Workability, Water Sorptivity, Compressive strength, Water absorption, Specific gravity, Apparent porosity of AAGGBFS pastes before and after exposing the test specimens to Sulphuric acid solution. Alkali content(Na_2O) varied from 4% to 10%, Silicate ratio varied from 0.8 to 1.2 and Water/GGBFS ratio varied from 0.35 to 0.30.

6.2 Based on test results the following broad conclusions can be made

1. Increasing the alkali content decreases the viscosity of AAGGBFS paste and results in an increase in the Workability using admixture 1.3% wt. of GGBFS. Maximum flow value 200 mm at Water/GGBFS is 0.35 and 225 mm at Water/GGBFS is 0.30. (Refer to Table 4.2.1.1.1 to 4.2.1.1.2 and Fig. 4.2.1.1.1)
2. Increasing the Silicate ratio from 0.8 to 1.2 increases the Workability of the paste at Water/GGBFS is 0.35 and 0.30. (Refer to Table 4.2.1.2.1 and Fig. 4.2.1.2.1 to 4.2.1.2.2)
3. The Sorptivity decreases with increase in alkali content because as alkali content increases the rate of reaction of GGBFS with activator solution also increases resulting in more gel formation which makes the Alkali Activated GGBFS pastes more compact thus containing less pore space up to 10%. (Refer to Table 4.2.2.1 to 4.2.2.2 and Fig. 4.2.2.1 to 4.2.2.2)
4. The initial rate of absorption (*Si*) and secondary rate of absorption (*Ss*) decreases with increase in alkali content varies from 4% to 10% at Water/GGBFS is 0.35 and 0.30 respectively. (Refer to Table 4.2.2.3 to 4.2.2.4 and Fig. 4.2.2.3 to 4.2.2.4)
5. Compressive strength Alkali Activated GGBFS pastes increases with increase in alkali content (Na_2O) from 4% to 10%. (Refer to Table 4.2.3.1.1 to 4.2.3.1.2 and Fig. 4.2.3.1.1 to 4.2.3.1.2)

6. Compressive strength maximum of 71.00 Mpa and 80.00 Mpa for silicate ratio (SiO_2/Na_2O) is 0.8 at water/GGBFS= 0.35 for 7 days and 28 days. Similarly 86.00 Mpa and 90.00 Mpa for silicate ratio (SiO_2/Na_2O) is 1.0 at water/GGBFS= 0.30 for 7 days and 28 days. (Refer to Table 4.2.3.2.1 and Fig. 4.2.3.2.1 to 4.2.3.2.2)
7. Water absorption decreases from 10.7% to 2.88% with increase in alkali (Na_2O) content from 4% to 10% at Water/GGBFS = 0.35 and from 3.03% to 1.90% at Water/GGBFS = 0.30. (Refer to Table 4.2.4.1.1 to 4.2.4.1.2 and Fig. 4.2.4.1.1 to 4.2.4.1.2)
8. It is also observed that Apparent porosity decreases from 18.58% to 5.69% with increase in alkali (Na_2O) content from 4% to 10% at Water/GGBFS = 0.35 and from 5.84% to 3.20% at Water/GGBFS = 0.30. (Refer to Table 4.2.5.1.1 to 4.2.5.1.2 and Fig. 4.2.5.1.1 to 4.2.5.1.2)
9. Change in shape and size is observed and the change in shape and size is more prominent with increase in Duration and Exposure condition in the paste specimens exposed to Sulphuric acid, though they were structurally stable.
10. Compressive strength of the paste specimens Exposed to Sulphuric acid decreases with both increase in Duration of Exposure and Concentration of Sulphuric acid. (Refer to Table 4.2.3.1.1.1 to 4.2.3.1.1.2, 4.2.3.2.1 to 4.2.3.2.2 and Fig. 4.2.3.1.1.1 to 4.2.3.1.1.3, 4.2.3.1.2.1 to 4.2.3.1.2.6, 4.2.3.2.1.1 to 4.2.3.2.1.3, 4.2.3.2.2.1 to 4.2.3.2.2.6)

6.3 Scope for future studies

The following are a few possible further studies.

1. Similar study on GGBFS mortar and concrete specimens under acid exposure and elevated temperature may be carried out.
2. Another area of study may be on behaviours of GGBS and Fly ash blended geopolymer.
3. Study of shrinkage and creep on GGBFS composites.
4. Detail study on durability of GGBFS paste i.e. May be exposed to acid, sulphate, chloride environment etc.

1. ASTM C 109/C 109M : “Standard Test Method for Compressive Strength of Hydraulic Cement mortars using 50mm Cube Specimens”.
2. ASTM C 1437-07 : “Standard Test Method for Flow of Hydraulic Cement Mortar”.
3. ASTM C 1585-04 : “Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes”.
4. ASTM C 230/230M: “Standard specification for Flow Table for use in Tests of Hydraulic Cement”.
5. ASTM C 494/C 494M: “Standard specification for Chemical Admixtures for Concrete”.
6. ASTM C 642-97 “ Standard test method for density , Absorption and Void in concrete” Section 4,V-04.02 pp. 185 – 198.
7. Bondar. D.: Lynsdale. C.J.: Milestone. N.B.: hassani. N.: ramezanianpour. A.A.: Effect of type, form, and dosage of activators on strength of alkali-activated natural pozzolans, Cement concrete res. 33(2), 251-260 (2011).
8. Cincotto. M.A.: Melo. A.A.: Repette. W.L.: Effect of different activators type and dosages and relation to autogenous shrinkage of activated blast furnace slag cement. In: Proceedings of the 11th International Congress on the Chemistry of Cement, Durban, pp.1878-1887 (2003).
9. Davidovits, J., “Global warming impact on the cement and aggregates industries”, World Resource Review, 6(2) (1994) 263-278.
10. E. Arioz, O. Arioz, O. Mete Kockar a, “An experimental study on the mechanical and microstructural properties of geopolymers” (2012) Vol. 42 : pp: 100 – 105.
11. F. Collins, J.G. Sanjayan, “Effects of ultra-fine materials on workability and strength of concrete containing alkali-activated slag as the binder”, Cem. Concr. Res. 29 (1999) 459–462.
12. F. Collins, J.G. Sanjayan, “Microcracking and strength development of alkali activated slag concrete”, Cem. Concr. Comp. 23 (2001) 345–352.
13. Hailong Ye, Christopher Cartwright, Farshad Rajabipour, and Aleksandra Radlińska, “Effect of Drying Rate on Shrinkage of Alkali-Activated Slag Cements” (2014).
14. J. Davidovits, “Geopolymer chemistry and sustainable development, the poly (sialate) terminology: a very useful and simple model for the promotion and understanding of green-chemistry”, Proceedings of 2005 Geopolymere Conference, 1, 2005, pp. 9–15.
15. Kong B. L.Y, Sanjayan J.G. and Sagoe-Crentsil Kwesi , “Comparative performance of Geopolymers made with Metakaolin and fly ash after exposure to elevated temperatures” Cement and concrete Research , 2007 , vol.37 No. 12, 2007 , pp.1583 – 1589.
16. Lee , W.K.W and Van Daventer ,J.S.J, “Structural reorganization of class F fly ash in alkaline silicate solutions, Colloids and Surfaces A Physicochemical and Engineering Aspects” , 2002 , No. 1 ,pp 49 – 66.
17. M. Chi, R. Huang, “Binding mechanism and properties of alkali-activated fly ash/slag mortars”, Constr. Build. Mater. 40 (2013) 291–298.

18. M.N.Qureshi and Somnath Ghosh, “ Effect of Fineness on Engineering Properties of Alkali-activated GGBFS paste”, *International Journal of Applied Engineering Research*, 8 (2), 2013, pp. 131-146.
19. M.N.Qureshi and Somnath Ghosh, “Effect of Silicate content on the Properties of Alkali-activated Blast furnace Slag Paste,” *The Arabian Journal for Science and Engineering*, 2013 (in press).
20. Mohd. Nadeem Qureshi and Somnath Ghosh, “Alkali-Activated Blast furnace Slag as a Green Construction Material” (2014), pp: 24-28.
21. Nath, P. and P.K. Sarker, “Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition”, Construction and Building Materials, 66 (2014) 163-171.
22. Neville, A.M., “Properties of Concrete”, 5th ed, Harlow, England; New York: Pearson, 2011.
23. P. Duxson, J.L. Provis, “Designing precursors for geopolymer cements”, J. Am. Ceram. Soc. 91 (12) (2008) 3864–3869..
24. P. K. Mehta, 3rd International Conference on “Fly Ash, Silica Fume, and Natural Pozzolans in Concrete”, Tronheim, Norway, 1989, pp. 1–43.
25. Pawel Lukowski, Ali Salih, “Durability of mortars containing ground granulated blast-furnace slag in acid and sulphate environment” (2015) Vol. 108 : pp: 47–54.
26. Qureshi. M.N.: Ghosh S.: Workability and setting time of alkali activated blast furnace slag paste. ASTM Int. J. Adv. Civil Eng. Mater. 2(1) (2013).doi: 10. 1520/ACEM20120029.
27. Ricarda Ta¨nzer • Anja Buchwald • Dietmar Stephan, “Effect of slag chemistry on the hydration of alkali-activated blast-furnace slag” (2015) Materials and Structures Vol. 48 : pp: 629–641.
28. Sathonsaowaphak. A.: Chindaprasirt. P.: Pimraksa. K.: Workability and strength of lignite bottom ash geopolymer mortar. J. Hazard. Mater. 168, 44-50 (2009).
29. Shi. C.: Li. Y.: Investigation on some factors affecting the characteristics of alkali phosphorus slag cement. Cement Concrete Res. 19(4), 527-533 (1989).

Sample calculation for different ingredient needed for producing GGBFS paste of specified parameters:

Parameter:-

% of Na_2O = 8

SiO_2/Na_2O in activator solution = 1

Admixture/GGBFS = 1.3%

Water/GGBFS = 0.30

Assuming quantity of GGBFS = 1000 gm

Quantity of admixture needed = 13 gm

Their fore quantity of Na_2O @8% of GGBFS = 80 gm

1000 gm Sodium silicate contents 265 gm of SiO_2 , 80 gm of Na_2O and 655 gm of water.

Their fore to get 80 gm of SiO_2 in activator solution

Quantity of Sodium Silicate needed = 301.89 gm

This amount of Sodium Silicate contents, quantity of Na_2O = 24.15 gm and water = 197.74 gm

Their fore rest of Na_2O = (80gm – 24.15gm) = 55.85 gm which was obtained from sodium hydroxide (NaOH) solution.

1000 gm Sodium Hydroxide in pellets form, content 775 gm of Na_2O and 225 gm of water

Their fore to get remaining 55.85 gm Na_2O in activator solution

Quantity of Sodium Hydroxide needed = 72.06 gm

Quantity of water present in 72.06 gm of Sodium Hydroxide in pellets form 16.21 gm

Their fore water from these chemicals = (197.74 gm + 16 21 gm) = 213.95 gm

To produce a GGBFS paste specimen of Water/GGBFS = 0.30, total water needed = 300 gm

Extra water that was added = (300 gm – 213.95 gm) = 86.05 gm

As NaOH pellets is 97% pure, considering this

Quantity of NaOH required = 74.23 gm