

# Durability of Alkaline activated slag concrete in Aggressive Acidic Environment: A Review

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**Abstract** – The most frequently using construction material on the planet is concrete. The environment is polluted by CO<sub>2</sub> emissions from the making of Ordinary Portland cement. One of the materials that could be utilised to effectively replace concrete is alkaline activated slag concrete. Alkaline activated slag concrete (AASC) is an inorganic alumino-silicate polymer consisting primarily of silicon, aluminium, and waste materials such as slag and fly ash. When compared to OPC, fly ash and slag are more environmentally efficient and sustainable less. With the increased deterioration of concrete, strength can no longer be use as the primary criterion for judging concrete quality. The concrete's strength and durability must both be proved. Dumped acidic effluents from companies have been identified. Acidic effluents from industries have been discovered to be dumped into the environment without being properly treated. Again, those acids may be natural in addition to inorganic acids. Organic acids are classified as susceptible acids, as opposed to inorganic acids, due to their partially dissociative nature. The mechanism of acid attack varies mainly depending on the type of acid and the properties of the calcium salt that can be formed. Traditional Portland Cement (OPC) concretes are not acid resistant. Additionally, as we move towards sustainable development, alkali-activated or geopolymeric concrete has started to gain interest due to its miles of higher mechanical residence time and strength compared to standard concrete. This article evaluates the damage mechanisms of sulfuric, hydrochloric, citric, nitric, and acetic acids in alkali-activated binders.

**Key Words:** Acid resistance, Durability, Fly Ash Geopolymer concrete, Alkaline activated slag concrete, Slag Geopolymer concrete, Alkaline activation.

## 1. INTRODUCTION

In today's society, concrete is one of the principal building materials. Due to greenhouse gas emissions as from production of concrete, which are a vital factor in global warming, the industry has a significant impact on the environment. The fundamental elements of concrete are cement, water, fine aggregates, and coarse aggregates. However, the PC is regarded as the primary source of gas emissions in the production of concrete, accounting for between 74 and 81 percent of the CO<sub>2</sub> emissions from typical concrete mixes [3]. Though many research studies have been performed on AAC as an alternative to PCC a few decades ago, it has gained popularity as a construction

material. Because AAC can be manufactured without the use of PC, it can be considered green concrete. AAC has been shown to have superior mechanical properties while also limiting CO<sub>2</sub> emissions. Furthermore, AAC emits less CO<sub>2</sub> than PCC. AAC not only reduces CO<sub>2</sub> emissions but also consumes a significant amount of industrial waste such as slag and fly ash. AAC is made up of alumino-silicate sources (such as ground granulated blast furnace slag (GGBFS), fly ash (FA), or silica fume (SF), alkali activators (such as silicates, hydroxides, or carbonates), water, and fine and coarse aggregates.

Concrete is a superior building material that has been widely used in the production industry worldwide. Due to the growth of business sports in urban areas, concrete systems are exposed to aggressive environments. Acid assault on concrete is a huge location wherein several researches has taken area due the non-stop deterioration of concrete systems resulting from those competitive species over time. Concrete is located to be in disequilibrium with its surroundings because of its alkaline nature. The Ca<sup>2+</sup> and OH ions must obtain described levels of attention for the hydrated compounds to be strong. Concrete deteriorates as a result of the hydrated compounds' hydrolytic decomposition, which causes distortion of the cement matrix as the pH of the solution actually reduces[5].

Acids that attack concrete is organic or inorganic in nature. The attack of organic acids is more complex within the food and agricultural industries. Corrosion causes to biological vitriol is one in all the fastest causes of concrete deterioration. Between 2002 and 2022, the us alone estimated \$390 billion to repair existing wastewater infrastructure thanks to bio corrosion[6]. The entry of those aggressive species can affect the porous network, the mechanical properties of the structure. the sort of acid, its concentration, the pH, the solubility of the salts formed are a number of the most factors that influence the aggressiveness of those species. Both organic and inorganic acids are structurally destructive, but there are differences in their decomposition mechanisms.

As of presently, critical amount of thinks about canvases is executed to upgrade concrete with modern creation substances emphasizing on maintainability, diminished carbon impressions, sturdiness and eco neighborliness. Antacid enacted or Geopolymer concrete has started out to

advantage intrigued as it's miles found to have higher mechanical homes and sturdiness assessing to conventional concrete. The covers utilized must be affluent in silica and alumina with diminish calcium substance. Impact heater slag, coal inferred fly fiery debris, calcined clays and home grown pozzolans are a number of the folios found to display fitting comes about[4]. But more prominent amount of thinks about canvases is ordinarily prescribed for forcing geopolymer concrete nearly since of its workability and putting time issues. In spite of the fact that geopolymer period has positive drawbacks, it has capacity to be a moo carbon impression texture opportunity to the conventional concrete. Thus, this paper exclusively portrays about acid mechanism on AASC in different environments like sulphuric acid, nitric acid, hydrochloric acid, acetic acid and citric acid.

## 2. SOURCES OF ACIDIC ENVIRONMENT

Acid attack is a common occurrence in industries that still use chemical acids for various processing. Acid discharge and improper disposal in such industries will result in rapid degradation of concrete components if acids gets in contact with them. One of the primary strong sources of concrete degradation is sulphuric acid. In general, aerobic bacteria in a sewer collection system react with hydrogen sulphide (H<sub>2</sub>S) gas to produce sulphuric acid (H<sub>2</sub>SO<sub>4</sub>). These acids then permeate the concrete, causing leaching and, eventually, concrete disintegration. The concrete inside biogas reactors digesters are also prone to deterioration due to the production of organic acids and ammonium in the liquid phase and H<sub>2</sub>S and CO<sub>2</sub> gases in the gas phase. The fertilizer manufacturing industries uses nitric acid and sulphuric acid in the production of ammonium nitrate and superphosphate fertilizers[2]. Industrial emissions of sulphur and nitrogen compounds, can be later converted to sulphuric and nitric acids and lead to acid precipitations with a pH level ranging from 5.0 to 3.0. Acidic rain or mist is then another aggressive agent for concrete structures [8].

Mechanical plants and production lines utilizing diverse forms utilize or create a assortment of manufactured acids. The coincidental spillage and spillage of these acids can truly harm concrete structures, as the concentration of acids assaulting concrete can reach disturbing values. Other than the real generation of these acids, the fertilizer industry employments nitric corrosive (HNO<sub>3</sub>) and sulfuric acid(H<sub>2</sub>SO<sub>4</sub>) or phosphoric acid(H<sub>3</sub>PO<sub>4</sub>) within the generation of ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>) and superphosphate (Ca (H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub>), separately[6-10]. The glass industry employments hydrofluoric corrosive (HF) as a destructive operator. Essentially, numerous acids take part in metal handling units. In specific, hydrochloric corrosive (HCl) is broadly utilized within the rust expulsion prepare within the steel industry to expel the rust layers on the steel surface. Superphosphate fertilizers utilized in agribusiness may have the nearness of free sulfuric and phosphoric acids. Sewage, beneath perfect conditions, can harm concrete sewer line. Fig 1 shows the production of sulphuric acid in sewage units.

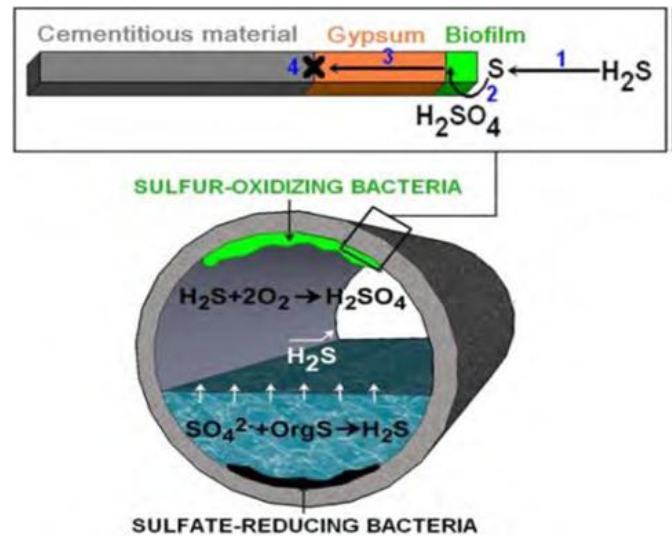


Fig – 1: Generation of sulphuric acid in sewage unit

In addition to sulphuric and nitric acids, industrial emissions of sulphur and nitrogen compounds may be oxidised and transformed. Because the pH cost is low, rain containing those acids will be destructive to cementitious materials (pH approximately 3-5). As a result, acid rain will be an additional competitive way for concrete structures[11]. Figure 2 depicts the formation of sulphuric acid and nitric acid, which results in acid rain.

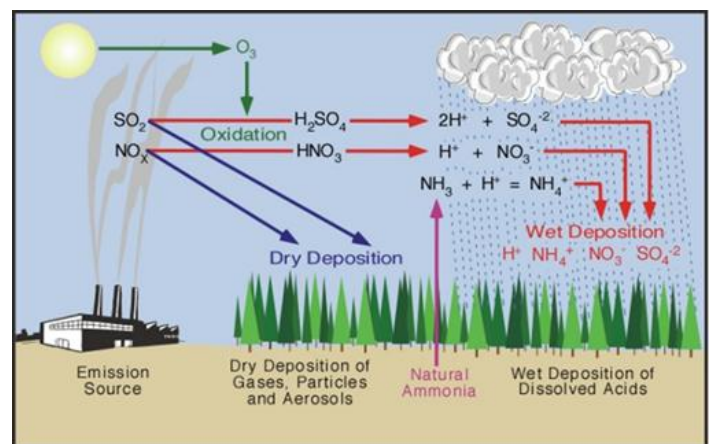


Fig – 2: Formation of acid rain

Organic acid attack takes place in industrial applications as well, but it is most commonly caused by effluents discharged in the agriculture and food industries. Depending on the type of wastewater output, this effluent contains organic acids such as acetic, propionic, tartaric, oxalic, lactic, citric, and others [13]. The production of organic acids and ammonium in the liquid phase, as well as H<sub>2</sub>S and CO<sub>2</sub> in the gaseous phase, can also damage the concrete inside the composting pit.

### 3. ALKALINE ACTIVATED SLAG COMPOSITES

#### 3.1 Historical Background of Alkaline Activated Slag Concrete

The first use of alkaline activated materials dates back to 1930, when Kuhl studied mixtures consisting of GGBFS and an alkaline solution of KOH. The reactivity of GGBFS using alkaline solutions of KOH and NaOH was studied by Chassevent in 1937[14]. In addition, GGBFS was activated by Purdon with NaOH solution in[15].

In 1959, Glushkovsky was the first to study the production of binders using a free or weakly basic calcium aluminosilicate source (clay) with alkaline activators [16]He developed a new binder named 'soil cement', soil referring to the appearance of crushed stone and cement referring to its adhesive ability.

In 1980, additionally Glushkovsky investigated the activation of GGBFS:(a) describing the hydration merchandise which consisted of calcium silicate hydrates and sodium aluminosilicate hydrates, and (b) reporting that the alkali-activated clay minerals fashioned aluminum silicate hydrates (zeolite)[20].

n 1984, Davidovits obtained a binder by mixing kaolinite, limestone, and dolomite with an alkaline solution. The resulting binder is called 'geopolymer' because of its polymeric structure (Timothy A. Aiken, Jacek Kwasny, Wei Sha,2021). In addition, it has released several brands for adhesives such as Geopolycem and Pyrament. Kyiv National University organized two international conferences on AAC in 1994 and 1999[18].

#### 3.2 Constituents of Alkaline Activated Slag Concrete

One or more sources of aluminosilicates and one or more alkaline activators constitute an alkaline activator system. The illustration in fig. 3 depicts the creation of alkali-activated material. High pH environments are developed by activation solutions (e.g. hydroxide, silicate, carbonate or sulfate). Pre-mixed dry materials made of the aluminosilicate source and alkali activator can then be combined with water and aggregates to establish mortar or concrete. Alternately, the alkaline activator can be added to the aluminosilicate source separately. This wet binder is then combined with additional water (if necessary to dilute the lye concentration), gathered, and used to make mortar or concrete. Aluminosilicate source, alkali activator, water, and aggregate can also be utilized to develop AASC.[13]. The Cementitious alkali-activated system components are shown in Fig. 4.

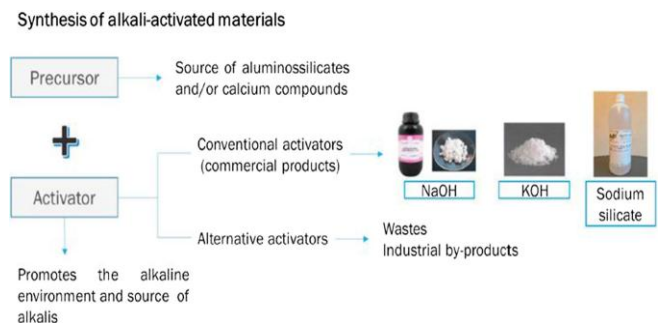


Fig - 3: Representation of synthesis of alkali activated materials

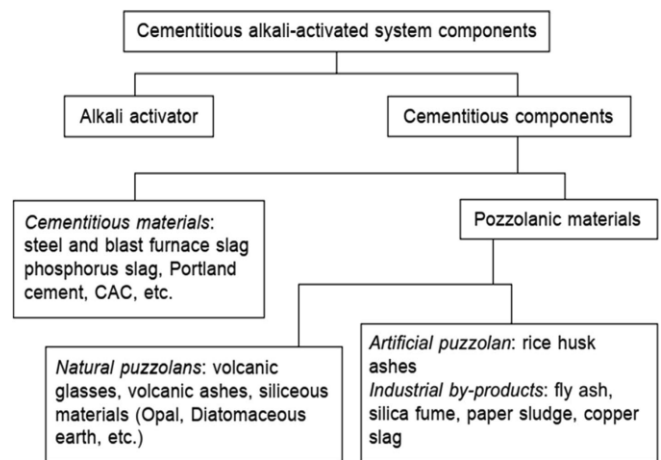


Fig - 4: Cementitious alkali activated system components

#### 3.3 Mechanism of AASC Composites

AASC are inorganic polymers that are amorphous rather than crystalline in nature. They are considered to be a subset of the alkaline activated binder system. Alkaline activation is the general term applied to the reaction of a solid aluminosilicate (known as 'precursor') under alkaline conditions (produced by 'alkaline activator'), to make a curing binder. on the combination of hydrated phases of alkaline-earth aluminosilicate and/or alkaline-earth aluminosilicate[17]. Geopolymerisation is an exothermic reaction in which a reaction occurs between silica (Si) alumina (Al) under alkaline conditions, which then produces a three-dimensional polymer chain linking Si-O-Al-O. The process of creating geopolymerisation includes a three-step reaction, which is Dissolved Coagulation, Coagulation, Condensation Polymerization[21]. The reaction rate is affected by condensation rather than dissolution. Ancient studies used geopolymers as fireproof coatings for cruise ships, heat-resistant adhesives, thermal protection of wooden structures, and more. Geopolymers differ in their reactivity and availability. Figure 1 illustrates a simplified reaction mechanism for geopolymerization of geopolymers. This figure depicts the conversion of a solid aluminosilicate to a synthetic alkaline aluminosilicate.

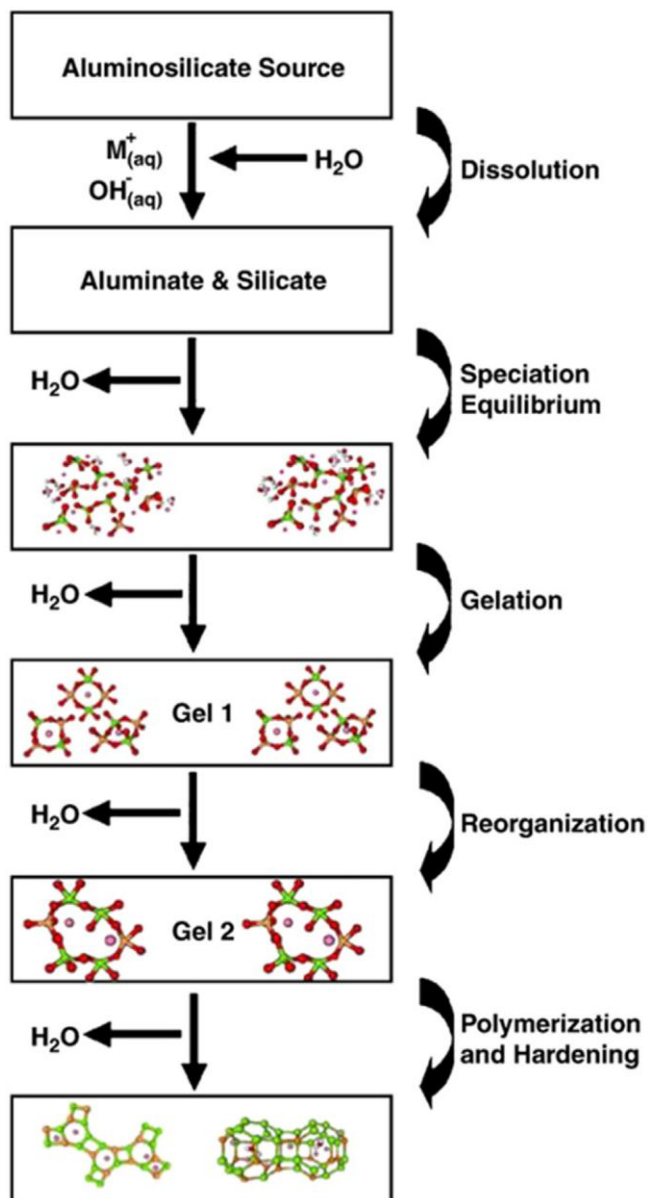


Fig - 5: Simplified reaction mechanism of AASC

The AASC raw material should be rich in aluminum and silica. The materials must be amorphous in nature as the degree of polymerization depends on it. AASC precursors can be natural pozzolanic materials such as volcanic ash, diatomaceous earth, shale, zeolite, kaolinite, phonolite, etc. or man-made materials including materials from industrial or agricultural waste such as low-calcium fly ash, silica fume, brick powder, granulated kiln slag, bagasse ash, rice husk ash, red mud, fluorescent lamp waste, ceramic waste, etc. The activators used in aluminosilicate precursors are alkali hydroxides, alkaline silicates, or a mixture of the two, to produce high alkalinity. The commonly used alkali activators are sodium hydroxide (NaOH) / potassium hydroxide (KOH) and sodium silicate ( $Na_2SiO_3$ ) / potassium silicate ( $K_2SiO_3$ ). The concentration and molarity of the solution affect the properties of the dough. The combination of NaOH and

$Na_2SiO_3$  is preferred because for  $Na_2SiO_3$  to be reactive, it must first be sterilized with NaOH[24]. The rate of the reaction is affected more by the condensation step than by the dissolution.

Potassium ions require a greater effort to penetrate through the paste due to its larger size than sodium ions and therefore sodium-based alkali activators are widely used[5]. Alkaline activators are difficult to handle in large quantities because they are viscous, corrosive, and hazardous. Solid NaOH is corrosive and forms sodium carbonate on contact with  $CO_2$ .

Sodium aluminosilicate hydrate (N-A-S-H) gel, the principal response manufactured from the alkali-activated aluminosilicates, differs of the aluminium-changed calcium silicate hydrate (C-A-S-H) gel of PC pastes. Fly ash and slag are determined to be the maximum capacity sources of AASC many of the waste products. High attention of calcium ion in elegance C Fly ash primarily based totally geopolymers can bring about better compression power[16]. But using elegance C fly ash primarily based totally precursors became determined because the causation of speedy setting. Gel composition in large part impacts the mechanical power and durability. The fundamental hydration product is a calcium silicate hydrate (C-A-S-H gel) with aluminium in its composition. The shape and composition of C-A-S-H gel and the presence of different secondary stages or compounds rely upon the kind and quantity of activator used, slag shape and composition and the curing situations wherein the cloth hardens [9]. When slag became in part changed through  $Ca(OH)_2$ , workability and compressive power became determined to be reduced[23].

Due to the hydrated slag formation of sodium calcium silicate, slag-based geopolymer concrete has a higher expansion rate than fly ash-based AASC. CASH gels are formed by alkaline activation of silica and calcium-rich materials such as slag and NASH gels are formed by alkaline activation of silica and alumina-rich materials such as fly ash and metakaolin[24]. The incineration of agricultural waste produces hulls and husk ash which are highly active silica-rich residues. China is the largest rice husk contributor with an estimated production of about 80 tons. The one-component geopolymer rice husk mixture activated with solid sodium aluminate was found to have a relatively high compressive strength (30 MPa)[14]. Although these ash sometimes contain large amounts of unburnt carbon, poor quality rice husk ash (which loses 40% on ignition) has been shown to be successfully used in single-component geopolymers[9]. Vincent et al. [11] used alkali-activated materials obtained from asphalt fillers and fluorescent lamps to verify the suitability of their use for urban pavements. Because the fluorescent lamp waste is rich in  $SiO_2$ , the flexural strength of the compositions is increased unlike that of the asphalt admixture waste containing  $CaO$  and  $MgO$ . Increasing the  $SiO_2/Al_2O_3$  ratio has a more positive effect on strength than asphalt fillers.

Alkaline activated binders can be manufactured as one part mixing system or two part mixing system. Two-part blends are commonly used for prefabricated construction work by most industries, as chemical treatment and handling regimes can be effectively tightly controlled [14]. In a two-part mixing system, in addition to water, a solid aluminosilicate precursor and an alkaline activator solution are required. Figure 2 shows a partial mixing system that, in addition to water, requires a dry solid mix.

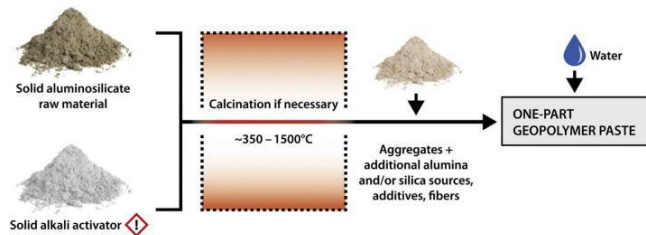


Fig - 6: Preparation of one part geopolymer

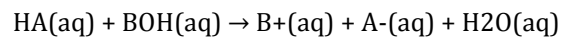
From figure 6, it could be referred to that the dry aggregate is ready through blending a strong alkali-activator at the side of a strong aluminosilicate precursor. Also the guidance of the dry aggregate can take vicinity without or with the calcination step. The activator in a one element geopolymer blend may be any substance that gives alkali cations, increases the pH of the response aggregate, and allows dissolution. For traditional geopolymers, alkaline activators may be focused aqueous answer of alkali hydroxide, silicate, carbonate, or sulphate [18]. Normally, one-element blend precursors used are fly ash (elegance F) in aggregate with blast furnace slag. Class C fly ash isn't distinctly advocated because it reasons speedy putting because of excessive quantity of calcium content. In a few researches in which mechano chemical activation approach turned into used wherein fly ash turned into ball-milled with dry combined activators are located to have excessive power, elevated resistance to moisture and great microstructure. One-element aggregate is located to have problems associated with power i.e. their power is located to be decrease not like two-element mixtures [3]. If problems associated with those may be resolved, then one-element blend will be a business fabric as it's miles dry, it could be packed into luggage and transported efficiently.

The process of creating geopolymerization often depends on the curing method. The curing method applied has a significant impact on the thermal properties of the AASC, the microstructural characteristics and the strength development. Curing temperatures between 40C and 85C have been shown to be almost perfect for genotyping. For fly ash geopolymers, temperature curing or furnace curing is usually applied. Nuruddin et al. [24] reported that for alkaline activated fly ash, curing temperature is critical to achieve higher strength and that test pieces subjected to higher curing temperature have higher mechanical strength than samples at low temperature. They also observed that

strength increased as the healing time increased, but the increase in strength was negligible when the healing time lasted beyond 24 hours. In the case of geopolymer concrete made with fly ash and activated with sodium hydroxide and sodium silicate solutions, the results showed that the seven-day strength of the kiln-cured samples was almost six times greater than that of the cured samples [1]. in the surrounding air. They found that the strength of geopolymer concrete improved at higher temperatures and the optimum strength was found to be 80°C for steam curing, while for water curing, strength was found. The intensity obtained after 28 days was lower than the characteristic intensity due to poor strength development. at lower temperature. The slag-based geopolymer was found to have lower strength at room temperature than the steam-treated samples. However, curing at high temperature for a long time leads to degradation of the sample due to thermal analysis of Si-O-Al-O silicate bonding [14]

#### 4. GENERAL MECHANISM OF ACID ATTACK

Concrete is a porous multi-phase material. The porous solution is alkaline (pH about 13) and hydration takes place in this porous solution. Therefore, due to its high alkalinity, the natural balance of concrete is disturbed when it reacts with acids. The compounds present in the binder as well as the acid-soluble aggregates (e.g. dolomite or limestone) are unstable in solutions containing an excess of hydrogen ions (acid). The attack is a classic acid (HA)/base (BOH) type reaction to form salt (BA) and water.



The product of Portland cement hydration has a strong acid reaction. The chemical stability of the material is governed by the chemical composition of the components of the hydrated cement paste and their relative proportions in the substrate. Portlandite is the least stable of the cement hydrates; Its dissolution occurs when the concentration of calcium ions in the interstitial solution falls below 22 mmol/L. CSH gels are more stable when the concentration of calcium ions in the interstitial solution is between 22 and 2 mmol/L, this also depends on the Ca/Si molar ratio of the CSH gel. When the concentration of calcium ions in the interstitial solution falls below 2 mmol/L, the CSH gel also becomes unstable; it undergoes calcification to eventually form silica gel, which is stable at low calcium concentrations in interstitial solution (Ramaswamy K P and M Santhanam, 2019).

The penetration of acidic ions into the adhesive matrix by diffusion disturbs the stoichiometric balance and this phenomenon is schematically shown in Figure 3. Dissociated cations from hydrates such as Ca<sup>2+</sup>, Al<sup>3+</sup> are wash away towards acidic solution with alkaline ions to maintain chemical balance. In this process, these cations such as Ca<sup>2+</sup> and Al<sup>3+</sup> can react with the anions of the acid to form salts of different solubility depending on the properties of the

acid[17]. The kinetics of the decomposition essentially depends on the different properties of the salts thus formed.

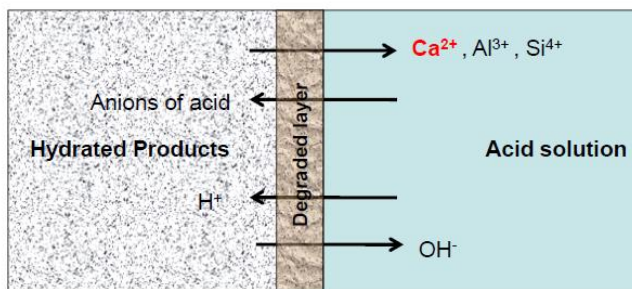


Fig – 7: Acid attack phenomenon

The chemical reactions within the paste are essentially of two types; the dissolution of hydrated and anhydrous stages within the binder matrix and the precipitation/leaching of latest response merchandise which are fashioned [6]. These reactions continue from out of doors to the interior, forming a degraded layer within the process. The physico-mechanical residences of the degraded layer are weaker in comparison to the sound zone. If the goods fashioned are soluble, they leach out into the answer growing the porosity of the matrix. Sometimes, if merchandise fashioned are much less soluble, those can also additionally precipitate within the matrix, exerting crystallisation stress ensuing within the formation of cracks. These cracks similarly lessen the mechanical energy and decorate the diffusion of acid to the inside. Eventually, the competitive retailers attain the reinforcement ensuing within the corrosion of strengthened structures. However, those are simple mechanisms of degradation; the degradation is especially depending on the kind of acid and the residences of the goods fashioned. Table 1 gives the solubility data of calcium and aluminium salts that may be formed when acid reacts with cement paste.

Table – 1: Solubility data of calcium and aluminium salts

| Acid         | Calcium salt   | Solubility at 20 °C (g/L) | Aluminium salt   | Solubility at 20 °C (g/L) |
|--------------|--|---------------------------|--|---------------------------|
| Sulphuric    | CaSO <sub>4</sub> ·2H <sub>2</sub> O   | 2.4                       | Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>                                  | 364                       |
| Hydrochloric | CaCl <sub>2</sub>  | 745                       | AlCl <sub>3</sub>  | 458                       |
| Nitric       | Ca(NO <sub>3</sub> ) <sub>2</sub> ·4H <sub>2</sub> O   | 1290                      | Al(NO <sub>3</sub> ) <sub>3</sub> ·9H <sub>2</sub> O                             | 673                       |
| Acetic       | Ca(CH <sub>3</sub> COO) <sub>2</sub> ·H <sub>2</sub> O   | 347                       | Al(CH <sub>3</sub> COO) <sub>3</sub>   | Sparingly soluble         |
| Citric       | Ca <sub>3</sub> (C <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ) <sub>2</sub> ·4 H <sub>2</sub> O | 0.95 (25°C)               | Al(C <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ) <sub>3</sub>                   | 2.3                       |
| Oxalic       | CaC <sub>2</sub> O <sub>4</sub> ·CaC <sub>2</sub> O <sub>4</sub> ·H <sub>2</sub> O               | 0.0067 (18 °C)/insoluble  | Al <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·4H <sub>2</sub> O | insoluble                 |
| Tartaric     | CaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ·4H <sub>2</sub> O                                | insoluble                 | -  | -                         |

According to Alexander and Fourie (2011), Portlandite (Ca(OH)<sub>2</sub>) is the maximum reactive of the hydrates and absolutely dissociates, even as calcium silicates are much less reactive observed through calcium aluminates and calcium aluminoferrites. The factors which include Ca, Na, K, Mg depart the matrix while Si, Al and Fe remain, the steadiness in their bearing stages considerably relying at the pH. A gel layer of particularly acid-insoluble silica (SiO<sub>2</sub>)

stays at the floor of the cement after the dissociation of calcium silicates. Aluminium hydroxide (Al(OH)<sub>3</sub>) and iron hydroxide (Fe(OH)<sub>3</sub>) precipitate within the layer after dissolution of the aluminates and aluminoferrites relying at the hydrogen ion awareness of the answer; iron hydroxide precipitates at a pH more than 1.zero and aluminium hydroxide precipitates at a pH more than 3.zero. More specifically, calcium hydroxide undergoes dissolution at a pore solution pH of 12.5, observed through ettringite at pH fee of 10.7. CSH gel turns into volatile and undergoes dissolution at pH between ~10.5 and 8.8 (in keeping with special authors) observed through calcium aluminate and ferrite hydrate stages. Eventually, the CASH gel is obtained, if the pH is above 7. If the pH is between 1 and 6, amorphous silica gel containing Al and Fe (SiO<sub>2</sub>·nH<sub>2</sub>O) will be obtained as a final product[5]. These microstructural changes due to hydrate fusion lead to the formation of the mineral partition; these changes manifest as changes in mass, strength, elastic modulus, etc. and the integrity of the matrix is affected. The loss of alkalinity of the substrate and thus increased porosity due to attack (due to osmosis of hydrates) eventually leads to corrosion of the reinforcements when the entire thickness of the concrete coating cardboard is attacked. However, this phenomenon is not straightforward, as the kinetics and mechanism of weathering degradation are affected by various factors related to the material, the corrosive solution and the test method.

#### 4.1 Sulphuric Acid Attack

The sulphuric acid first reacts with the calcium hydroxide found in concrete to supply gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O). Gypsum isn't always a great deal soluble in acid answer and stays as a precipitate within the concrete floor consequently lowering the penetration of acid within the early publicity period. This gypsum produced reacts with the calcium aluminate hydrate gift within the cement to supply ettringite (3CaO·Al<sub>2</sub>O<sub>3</sub>·3CaSO<sub>4</sub>·32H<sub>2</sub>O), which may be very negative to the hardened concrete. The full-size mass advantage of all mixes on publicity to sulphuric acid, particularly on the early age of publicity, became attributed to the gypsum formation across the specimens. The interfacial transition zone (ITZ) with excellent aggregates of an Alkali activated (AA) pattern after immersion in sulphuric acid confirmed comparable shape in morphology from that earlier than immersion, indicating that AA paste remained in true shape beneath sulphuric acid attack[15]. In the take a look at performed via way of means of Gu et al. 2018, demarcates the preliminary scanning electron microscopy (SEM) evaluation of AA fly ash matrix which includes a dense shape of sodium aluminosilicate hydrate (N-A-S-H) earlier than immersion in which the atomic ratio of silicon and aluminium became 1.5. When N-A-S-H is dissolved in reaction with sulfuric acid, the atomic ratio of silicon and aluminum increases to 2.3. For higher concentrations of sulfuric acid, it was found to dissolve the NASH gel, thereby reducing the compressive strength of geopolymer concrete.

Reju, 2019 found that the degradation progressed inward as the exposure time increased. The variable depth variation of the specimen before and after acid etching is an indicator of phenolphthalein that has been sprayed onto the freshly cut surface. Areas in pink indicate areas unaffected by acid exposure.

Unlike other acids, specimens immersed in sulfuric acid (concentration 0.5M) had a colorless surface indicating that they were completely decomposed by acid attack. The fly ash-based geopolymer (FGP) upon visual inspection showed no color change or salt deposition on the specimen, while the slag-based geopolymer (SGP) showed color change (Athira Ajay, K P Ramaswamy, Anu V Thomas, 2020). The mass reduction of the FGP samples was less than that of the OPC, indicating that the geopolymer samples are more resistant to acids than the others[13]. No mass loss was observed for SGP samples exposed to 0.25M acid. The FGP samples were found to be more resistant to sulfuric acid attack due to the better structural structure obtained after high temperature hardening.

#### 4.2 Citric Acid Attack

Citric acid is said to be the most active of the organic acids and sheds thickness rapidly. The high concentration used, the poly acidity of citric acid and the non-protective character of the precipitate formed appear to have increased the aggressiveness of citric acid. According to Koeing et al. the greater harmful effect could also be due to the acid buffering action of organic acids. According to Ramaswamy and Santhanam, the decomposition kinetics of citric acid strongly depends on its concentration. A large amount of white salt was precipitated on the samples soaked in citric acid and confirmed as calcium citrate tetrahydrate ( $\text{Ca}_3(\text{C}_6\text{H}_5\text{O}_7)_2 \cdot 4\text{H}_2\text{O}$ ) by X-ray diffraction study (Ramaswamy K P and M Santhanam, 2019). This salt has less solubility and very high molar volume than portlandite and CSH gels and has therefore been shown to be harmful to adhesive substrates.

In the have a look at with the aid of using Reju, 2019, non-stop publicity of FGP specimens in citric acid did now no longer display any structural disintegration. Severe cracking of SGP paste specimens have been determined because of the formation of low soluble loosely adhered white precipitate. SGP specimens from determine three are discovered to have decrease charge of deterioration as a purple shade is discovered closer to the core. However, effects from the microstructural evaluation confirmed that, FGP specimens has a higher overall performance in resisting citric acid as no expansive merchandise have been fashioned not like OPC and SGP.

#### 4.3 Nitric Acid And Hydrochloric Acid Attack

Nitric acid attack is a typical acid corrosion that causes a reduction in the volume of the corroded layer due to the

leaching of the highly soluble nitrate calcium salts. Blast furnace fly ash geopolymers corrode when immersed in nitric acid solution for a period of one month. This is due to ion exchange reactions between the skeleton charge-compensating cations (i.e. sodium, potassium or calcium) and the H ions present in solution. It could also be due to the electrophilic attack of the Si-O-Al macromolecular bonds by acidic protons, which causes the ejection of the tetrahedral aluminum from the aluminosilicate framework. It is observed that all mixtures exhibit mass loss due to progressive leaching of the hydrated phases since leaching is predominant during nitric attack.

The worst case state of affairs from the above discern is while OPC specimens are subjected to hydrochloric acid because it reacts with calcium compounds (along with Portlandite and CSH gel) main to the formation of calcium chloride, which has extraordinarily excessive solubility in solution. Geopolymeric mine waste binders have low acid resistance overall performance while as compared to geopolymeric binders primarily based totally on metakaolin[9] however universal geopolymer binders had higher resistance while as compared to OPC.

#### 4.4 Acetic Acid Attack

Acetic acids are determined specifically in waste waters and it's miles determined to be competitive in terms of acid attack. The corrosion system is speedy similar to that of robust acids inclusive of sulphuric acid however lesser competitive in comparison to citric acid at equal concentrations. These acids produce soluble calcium salts with the aid of using dissolution of calcium hydroxide in concrete. In the case of OPC specimens, orange yellow coloration turned into discovered at the specimens with none precipitation of salts. No precipitation or extrade in thickness turned into discovered for geopolymer specimens even in 0.5 M or 0.25 M acetic acid solutions[13].

The FGP samples showed superior acid resistance performance related to the weight loss (0.8 %) in the mortar samples exposed to 0.5 M acetic acid. The mass loss for the SGP sample was detected is currently higher than that of the FGP sample. In SGP concrete, the lower CH content and C/S ratio in the hydration products and the formation of silica gel (alumino) during decalcification hindered the penetration of acids and contributed to the potential greatest acid resistance of SGP concrete. Acid penetration is also hindered due to the finer pore structure of SGP concrete. [18]when evaluating the degradation kinetics of alkaline activated concrete exposed to organic acid attack demonstrated that the residual strength decreased as the Ca content of the binder increased. The organic acids studied were a mixture of acetic, lactic and propionic acids with a solution pH of 3.

The resistance decreases continuously with time, for all samples immersed in organic acids, with the exception of AAFA (alkaline reactive fly ash). Acid-exposed alkaline

activated fly ash samples showed a steady increase in intensity over time. Reju, 2019 also observed improved performance of sneak ash geopolymer when exposed to acetic acid solution.

## 5. CONCLUSIONS

Acid assault is a complicated phenomenon bobbing up in creation industries global as it's miles chargeable for the deterioration of concrete in acidic environments ensuing in untimely degradation in phrases of microstructural alteration of levels manifesting withinside the shape of mass changes, weakening of mechanical properties, boom in porosity because of calcium leaching etc. This complex mechanism of decay through numerous acids remains now no longer nicely understood and similarly explanation is important on this regard. Currently, there aren't any codes or requirements to be had for comparing resistance of substances to acid assault. Further research is vital to research and make clear the mechanisms of deterioration and alteration kinetics in those situations via way of means of growing dependable take a look at techniques and thus, to layout substances that carry out properly in those environments.

Both natural acids in addition to inorganic acids fluctuate of their mechanism of decay of concrete. The charge of decay is located to be depending on the kind of acid, awareness of acid, chemical composition of binders and solubility and traits of the salts shaped. Based at the aggressiveness of acids, sulphuric acid and citric acid are located to be the maximum competitive from maximum of the studies. On publicity to sulphuric and citric acid, expansive salts with excessive molar extent have been shaped inflicting fast degradation. Fly ash primarily based totally geopolymer confirmed incredibly stepped forward overall performance towards sulphuric, acetic and citric acid assault. Nitric acid assault on metakaolin geopolymer did now no longer have intense degradation on assessment to different waste binders used. Fly ash-slag primarily based totally geopolymer composites cured in ambient situations had similar overall performance to that of fly ash primarily based totally geopolymers cured at excessive temperature. The additions of small quantities of slag to fly ash primarily based totally geopolymers also are located to beautify its compressive power on publicity to acids.

The improved enlargement of city regions and proliferation of industries have caused the big scale technology of acidic media. This has caused extreme degradation of concrete systems made with OPC whilst it receives in touch with the acidic solutions. As of now, big numbers of researches are performed in changing cement in concrete with new binders emphasising on sustainability, decreased carbon footprints, sturdiness and eco-friendliness. Reinforcing the usage of supplementary cementitious materials (SCMs) as alkali activated binders could be a higher answer in presenting a sustainable concrete (100% substitute of cement), and

stepped forward resistance towards harsh competitive environments. From maximum of the studies, it's miles obtrusive that sturdiness overall performance of geopolymers are located to be superior. Thus alkali activated binder structures can provide a sustainable and sturdy opportunity to Portland cement primarily based totally structures for publicity in competitive acidic environments.

Although referred to as a weak acid, acetic acid can cause a rapid increase in the depth of weathering of the sample, and the stability of various binder systems in this acidic medium is often not studied in detail. The development of acid attack mechanism and prediction of degradation depth in a certain time, study of the effect of acid mixture and the effect of curing pattern on reaction rate are some additional studies. Supplements need to be considered to understand the broader aspects of acid attack and its degradation mechanisms.

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