Alkali silica reaction in geopolymer recycled aggregate concrete

Final Year Project Thesis UG-2017

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NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Science and Technology Islamabad, Pakistan

This is to certify that the Final Year project

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has been accepted towards the requirements

for the undergraduate degree

in

CIVIL ENGINEERING

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DEDICATION

We would like to dedicate our works to our parents, our teachers, our institution NUST and all our friends. We executed the work with the impressive assurance and determination and applied the best of ourselves to the errand at hand.

DECLARATION

It is hereby reverently and truthfully declared that all the work alluded to this thesis is composed by us and it has not been submitted by any institution, in whole or in part in any previous application for a degree. Any references to the work done by any other person or University have been appropriately cited.

ACKNOWLEDGEMENTS

"In the name of Almighty Allah, the Most Beneficent, the Most Merciful", first, we would like to thank Allah Almighty who enabled us to successfully complete our project as planned. We are extremely obliged to our project supervisor, Lecturer Sara Farooq for her keen interest, instruction, confidence, and supervision during the entire tenure of our project. She helped us tackle various problems and assisted is in achieving our goal. We are very thankful to Dr. Hammad Anis Khan for the professional counselling and guidance in the completion of this project. His provision of various research papers about geopolymer concrete greatly helped us in achieving the accuracy in our analysis. He helped us steer out the problems that we faced during our project. Lastly, we would like to thank all the researchers and engineers whose valuable literature helped us achieve this milestone.

ABSTRACT

This thesis states the outcomes of an experimental study aimed to compare alkali silica reaction's (ASR) mechanism by evaluating its damage in conventional concrete and geopolymer concrete. Geopolymer mortar specimens were prepared using fly ash of class F, slag with natural and recycled aggregate. Mechanical tests included accelerated mortar bar test, tests for compressive and flexural strength which were conducted according to ASTM standard. Findings suggested that in the presence of reactive aggregates, the extent of ASR reaction in geopolymer mortar which is based on fly ash is six times lesser than the mortar, which is based on OPC, and significantly below 0.11% which is the threshold specified by ASTM. Additionally, samples consisting of geopolymer mix turned out to go through a densification process during the existence of alkali solutions, due to which permeability was decreased and mechanical strength. The results show the mechanical properties are same for both OPC and GPM. Using aggregates which are at risk of having ASR while creating geopolymer concrete items can add to the financial allure and sustainability of geopolymer concrete in areas where the local supply of aggregates having high quality is lower.

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CHAPTER 1: INTRODUCTION AND RESEARCH OBJECTIVES

1.1 GENERAL

The material which is extensively utilized for building is concrete. In fact, annual concrete usage is expected to be second only to annual water consumption (Neves 2016). Its remarkable durability and ability to mold into the right shape are the reasons behind this. As the principal component of concrete, Ordinary Portland Cement (OPC)which is mostly utilized material in the world, with over a billion tonnes utilized in 2016. (CEMBUREAU 2016; Nath 2014). Because of its negative consequences, such as emission of greenhouse gases, dwindling of natural resources, and excessive use of energy, public has become painfully conscious with need of finding a substitute for OPC.

However, over the last few decades, the large carbon footprint and embodied energy associated with OPC has sparked a wide debate about the adaption of substitutes to OPC which are maintainable as well as environment friendly. Geopolymer concrete is being studied as a replacement for OPC concrete and is gaining traction in research and industry. An aluminosilicate materials like fly ash and crushed slag in combination with alkaline solutions forms geopolymer concrete.

Along with producing a concrete with less carbon emissions and low consumption of energy as compare to OPC, GPC shows comparable properties like better mechanical strength, lower value of shrinkage, fantastic resistance to creep, low ASR and enhanced durability during acid environment.

Aggregates are the major constituents of Geopolymer concrete. Due to the increased demand of concrete because of growing construction needs, the natural aggregates quantity is becoming low which is a very significant problem. In the meantime, extreme waste of construction and demolition has piqued the interest of society, the economy, and the environment.

The disposal of these solid wastes would not only take up a lot of room, but it would also result in carbon emissions, which would be another environmental issue. In fact, the majority of C&D wastes are made up of renewable materials such as bricks, stones which are naturally occurring and concrete which is wasted among others. Subsequently it is maintainable method of civil engineering to use this C&D waste in place of natural aggregate (either partially or fully) as recycled aggregate. So for recycled aggregate, first we crush the waste, then sieve it, then classify the aggregate to use in place of naturally occurring aggregate for the concrete and is the most scientific and successful way at this time.

Recycled aggregates can be subdivided into recycled brick aggregates, recycled mixed aggregates or recycled concrete aggregates as shown in the figure below:

FIGURE 2-1.1 MAIN CATEGORIES OF RCA

Materials like blocks of wood, scraps of paper, plastics and many different pollutants are also a part of RA. Currently, recycled aggregate extracted by crushing the concrete is the widely used RA in construction and specifications have been developed in organizations in different countries.

To produce concrete composites, brilliant attempts were made to employ RA obtained using C&DW. According to the literature, RA concrete has worse durability and mechanical qualities than normal concrete. The qualities of the resulting RA concrete are influenced by a variety of factors, including the quality and quantity of RA, w/c, the technique used for mixing and use of the certain types and admixtures.

The ill effects of RA on geopolymer mixes is same as compared to that on OPC. Nevertheless, because of the nonidentical formations of matrix, the geopolymer paste consists of more uniform and denser substance, leading to the recycled aggregate composites having higher strengths [8].

Despite the improved performance and sustainability of geopolymer recycle aggregate concrete (GPRAC), it has still not been recognized for its utilization as feasible construction materials. It is because of the few technical barriers which are left such as high temperature required for fabrication and curing.

In structural concrete with steel reinforcement, the most common deterioration causes are:

1. Penetration of chloride and carbonation, which leads to corrosion of steel resulting cracking.
2. inadequate cover to reinforcing steel Less common causes of deterioration
3. Thawing and freezing effect
4. Sulphate attacks
5. Aggregate-Alkali reaction

Alkali silica reactions and alkali carbonate reactions are the two types of Alkali-Aggregate reactions. When developing concrete structures with design life of nearly a hundred years, durability is an important consideration. ASR and freezing and thawing (F/T) durability concerns in concrete evolve with time, reducing the structure's usable service life. Deterioration can occur when the concrete's ingredients aren't able to withstand the exposure circumstances.

According to some theories, due to the high alkalinity of the activator, concretes which are alkali activated may be more susceptible to ASR than OPC. Alkali-activated binders, on the other hand, are devoid of the Calcium ion, which is necessary for the development of ASR gel, and hence may be resistant to any issues. Researchers have conducted various studies to verify ASR in AAC systems. The goal of this study is to add to the existing body of knowledge about the presence of ASR in concrete systems which are alkali activated and compare it to the Alkali Silica Reaction that occurs in regular concrete.

1.2 BACKGROUND

Alkali aggregate reaction (AAR) is a long-term durability issue in concrete that occurs because of the development of the hydroscopic gel due to a chemical reaction between reactive phases of aggregates and alkalis from cement paste (Hobbs 1988; Glasser and Kataoka, 1981).

Stanton (1940, 1942) of the California State Division of Highways was the first to notice the insane interaction between alkali and silica in concrete pavement. Internal expanding pressures emerged, which no known method could explain. Stanton (1940) began testing the materials which are being utilized for making concrete in the lab. Several conditions for curing, such as soaking, drying, and high temperature were tried, but no significant expansion was seen. Comparable specimens with high alkali cement and held in high humid conditions, on the other hand, had significant expansion after a year. It was observed that by using low alkali cements, there was negligible expansion.

Stanton's studies led to three conclusions: first, when specific minerals in aggregates are combined with high alkali cement, they expand excessively. Second, when alkali levels in cement were less than 0.60 percent, expansions caused by ASR in damp mortar bars appeared to be minimal. As a result, a restriction (to ward off concrete having these aggregates from expanding) of 0.6 percent cement alkalis was proposed . The result was that by partially replacing high-alkali cement with a suitable pozzolanic material, significant expansions might be avoided. 25 percent pumicite, a pozzolan, “seems to be effective” in decreasing “the expansion to a minimal amount at early periods,” according to Stanton (1940, 1942). Pozzolan was recommended to be used to prevent excessive expansion due to ASR, and it appears that Hanna was the first to propose it (1947).

As a result, all this effort has created the fundamental principles for controlling the expansion reaction. This work also served as the foundation for ASTM C 227, Mortar Bar Test Procedure. The US Bureau of Reclamation (Meissner, 1941) investigated anomalous cracking in concrete dams based on Stanton's findings. Meissner's conclusions mostly agreed with Stanton's, and he emphasized the relevant alkali level of cement, composition of aggregate, and environmental conditions in the growth of ASR expansion. One of the outcomes of this study was the creation of ASTM C 289, which is a fast chemical test (Mielenz et al., 1948).

The use of waste materials like fly ash and GGBFS as replacement for OPC in concrete to enhance its properties and reduce the environmental impact have been well established for decades. In alkali-activated cement, OPC is fully replaced by fly ash and GGBFS with alkali source as the activator. Even though the alkali activation technology was introduced back in 1908 by Kuehl, it got greater attention in the late 1970s when Davidovits discovered the geopolymer binders, more stable subcategory of alkali-activated materials (AAM) (Davidovits 2008; Provis 2014).

The mechanical properties, bond qualities, and workability of geopolymer-based concrete were considered to be equivalent to the properties of concrete based on OPC. Geopolymer concrete's socioeconomic and environmental aspects have been thoroughly examined in recent years, paving the way for it to be used as a viable substitute to OPC. Furthermore, many experts believe that geopolymer concrete will be able to withstand most of the durability difficulties that have been observed for OPC concrete, such as ASR (Aldred & Day 2012; Law et al. 2015; Singh et al. 2015; Van Deventer et al. 2007).

Colangelo et al. further stated that for lessen the OPC concrete’s environmental impacts, a more ecologically affable path must be explored, which includes the utilization of aggregates and binders in mix that are eco affable. As a result concrete made up of geopolymer and RA is a capable new environment affable material that will not only decrease pollution and consumption of raw material but, will also has the potential to perform well.

Safiuddin et al. investigated the use of coarse aggregate (recycled) in concrete, either in proportion or completely. Physical, mechanical, durability, and chemical qualities were the main focus of their research. They also identified the areas that needed to be investigated further. Geopolymer concrete’s strength in compression, Young’s modulus and poisons ratio using RA (coarse) decrease as the w/c proportion of geopolymer mix with RA (coarse) enhances, according to a study by Zhen et al. When minimal w/c proportion is used, geopolymer concrete has greater mechanical qualities than standard Portland concrete. As a result, in this work, recycled coarse aggregate was used to replace natural aggregate (coarse) in geopolymer mixes by replacing50% and 100%, respectively. C&DW provided the RA for this project. The major binder, fly ash, was combined with GGBFS in order to improve the characteristics of composites. Based on the findings, the effects of RA and GGBFS combination on several physical properties such as density, setting time, workability, absorption of water, and voids volume and mechanical properties such as strength in compression, modulus of elasticity, strength in flexure and split tensile strength of geopolymer mixes have been discussed.

Since 1974, eight international conferences on the AAR have occurred. Despite a large body of literature on the alkali silica reaction, it is still poorly understood in recycled aggregate concrete because ASR expansion is affected with a variety of additional factors such as the aggregate's initial reactivity, exposure temperature, moisture, alkali salts, and renewed reaction sites. Indeed, the alkali silica reaction is occasionally blamed for deterioration that might be attributable to other causes due to a lack of knowledge of the intricacy of the factors involved.

The mechanism of ASR and how to prevent it in Portland cement binders are well established. ASR in fly ash and GGBFS based concretes which are alkali activated, on the other hand has very little literature. A lot of researchers have looked into the incidence of ASR in AAC systems, however there are no conclusive findings in the literature. Alkali activated mortars shrank when tested using the ASTM C227 AMBT method, whereas mortars based on OPC grew greatly during similar circumstances, according to Davidovits. Jimenez hypothesized that mixes which are activated using alkali when revealed to these procedures would expand, but it would be considerably smaller than in OPC. ASR might develop in concrete based on slag which is alkali activated with siliceous aggregate, which is reactive, according to Puertas. Gifford and Gillott used material from six sources in Canada to conduct routine dimensional change experiments on OPC and alkali activated slag concrete, concluding that concrete based on slag which is alkali activated is less vulnerable to detrimental expansion owing to ASR than OPC. Since hydration products bind eighty percent of the alkali in 1 year, Wang determined that AAS concrete has no AAR. Garcia-Lodeiro also discovered that concrete based on fly ash which is alkali activated has a lesser ASR extent than OPC under ASTM C1260 test technique, and they established that calcium is important during the ASR gel expansion process. Bakharev, on the other hand, discovered that alkali activated slag concrete expanded more than OPC under the long-term ASTM 1293 technique, and decided that the binder system which is alkali activated has more susceptibility to ASR than OPC. In terms of aggregate type effects, Puertas also said that in mixes which are activated by alkali, siliceous aggregates are highly susceptible to ASR than calcareous aggregates. The mortar’s linear expansion is used for indicating the ASR’s incidence in the majority of these investigations, despite the fact that the exposure conditions vary. However, no solid findings could be drawn from the literature, hence the subject of AAC's vulnerability to harmful ASR is still up for debate.

1.3 OBJECTIVE

This research aims to assess the ASR’s risk in geopolymer mixesprepared using fly ash and GGBFS as aluminosilicate source materials with recycle aggregate. Comparison of ASR in alkali activated cements with various compositions of fly ash and slag with recycled aggregate in contrast will be studied. The following objectives were defined in order to achieve this goal.

1. To compare and contrast the mechanisms of ASR in Geopolymer and concrete based on OPC.

2. Investigate ASR in geopolymer concrete made with both natural and recycled particles.

3. Evaluation of mechanical properties both before and after alkali exposure.

4. Comparing the ASR and mechanical properties of GPC produced with varied quantities of fly ash and slag

5. Examining the difference in concrete strength owing to the usage of natural and recycled aggregate.

1.4 SCOPE OF STUDY

This study is intended to explore ASR in geopolymer concrete. Accordingly, chapters in this report provide an overview of the nature of ASR on both Portland cement concrete and geopolymer concrete.

Despite number of investigations describing ASR's mechanism in OPC mixes, relatively limited discussion about ASR in geopolymer mixes are reported. This investigation looks for identifying the damage because of ASR in geopolymer recycle aggregate concrete (GRAC).

This study will evaluate extent of ASR using AMBT as well as evaluate damage by comparing residual compressive strength and flexure strength test. Expansion test developed based on the accelerated mortar bar test (AMBT) was adapted in this study to compare the degree of ASR in different concrete mixture (geopolymer concrete with natural and recycle aggregate and OPC concrete with natural and recycle aggregate) which were further discussed in Chapter 3. Even though it is widely accepted that the severe exposure conditions in accelerated mortar bar test might over predict the reactiveness, it should be noted that the prime focus of this investigation is to assess the reactiveness of geopolymer concrete with natural and recycle aggregate and OPC concrete with natural and recycle aggregate and to determine which concrete mixture performs better against alkali silica reaction. In fact, short testing period in AMBT compared to concrete prism test (CPT) would allow to cover significant number of parameters even with extended testing time which would be an additional advantage in achieving the main goal.

For AMBT, 25x25x285 mm mortar bars were casted and tested using ASTM C 1260. GGBFS and fly ash having low calcium content were used which were bought from a supplier in Lahore.

Sodium silicate (Na_2SiO_3) solution and sodium hydroxide (NaOH) solution combination was utilized as the alkaline activator. Three aggregates were used in the study Margalla crush, crushed OPC concrete samples (RA) and glass aggregate.

Mix designs including three main geopolymer mixes with slag replacement percentages as 0%, 25%, and 50% including natural aggregate, 100% replacement of NA with RA and glass aggregate were used during this study. Similarly, OPC samples were prepared using the three types of aggregates.

In geopolymer mixes, all the ratios except water to binder ratio were kept constant while deviator mixes were developed while changing fly ash/ GGBFS content to gain high strength geopolymer concrete. For accelerate mortar bar test (AMBT), the length changes in the mortar bars were measured periodically. Compressive strength variation over the initial 28 days was measured as well.

1.5 RESEARCH SIGNIFICANCE

The environmental risks linked with the OPC's production are well-known. Because it produces 5% of the total CO2 produced globally, it is one of the key greenhouse gases that contributes to global heating. Simultaneously, conventional coarse aggregate's overuse exacerbates its scarcity. RA grabbed from destruction sites can alleviate the scarcity of NA (naturally occurring aggregate) and might be used to replace conventional materials in concrete production. Geopolymer concrete is a cost-effective and environmentally friendly alternative to traditional concrete.

Raw materials are limited, and their overutilization by some businesses and persons has presented a serious threat to ecology and atmosphere.

Another problem with concrete is the ASR, which is a delayed chemical reaction that happens in the presence of water between alkaline cement and reactive silica in aggregates. ASR generates a gel that expands, generating minute fissures in the concrete that affect its qualities. A good substitute for geopolymer concrete is geopolymer concrete, which can help to reduce the impacts of ASR.

1.6 RESEARCH ISSUES

Numerous research problems were faced during the research mainly they can be categorized into two categories.

1. COVID-19 pandemic
    - (i) Availability of material
    - (ii) Availability of lab testing equipment
    - (iii) Time constraint
2. Financial constraint

1.6.1 COVID-19 PANDEMIC

On December 31, 2019, it was declared by China that a new virus is spreading in the state of Wuhan and was named COVID-19 this virus then started to spread in different which until March was declared a pandemic by WHO (World Health Organization). Due to lockdown imposed by the Government of Pakistan, the related experimental stage was delayed. The lack of face-to-face meetings hindered effective communication among the syndicate members. In August 2020, the university was re-opened, but this research progressed at a slow pace due to 50% attendance policy imposed by the Government. Group and progress meetings were held after office timings and lab access was restricted to alternate days.

1.6.2 AVAILABILITY OF MATERIAL

Procurement has been a challenge since the material required for this project is rarely used in Pakistan’s construction industry. Furthermore, with ports being closed due to the lockdown, restocking of material was delayed. Moreover, communication with merchants had been done via phone only which might be the sole reason behind the material being delivered in raw form.

1.6.3 AVAILABILITY OF LAB TESTING EQUIPMENT

Testing equipment is essential when working on a research project. Simple devices for basic material tests were available but molds for ASR tests were not enough. A 16-gauge steel sheet was used to make those molds by press forming.

1.6.4 TIME CONSTRAINT

The COVID-19 pandemic caused significant delays in this research, from acquisition through experimentation. The concrete prism test, which was part of this study, required a one-year timeframe and was later eliminated owing to time constraints. Instead, the ASR expansion was measured using an accelerated mortar bar test.

1.6.5 FINANCIAL CONSTRAINT

There were limited funds available for the project, shortage of material resulted in increased demand which simultaneously increased the cost. Thus, the scope of the project had been reduced accordingly.

1.7 THESIS OUTLINE

- Chapter 1 contains a brief background study, research objectives, scope of the project and research significance.
- Chapter 2 delivers a complete review of the research's present state. It commences with a brief investigation of the general chemistry and properties of geopolymer binders and recent development in the understanding of AAR. Existing studies on AAR in geopolymer binders and the test methodologies currently used to identify alkali

aggregate reaction in concrete are extensively reviewed with respect to available literature and case studies

- Chapter 3 describes the relevant details of materials, sample preparation, mix designs used in this study, calculated quantities of materials, number of samples casted, instrumentation and data acquisition and details of the experimental procedure adopted.
- Chapter 4 presents the experimental results of the material testing on cement, sand, fly ash, slag and recycled aggregate. This chapter contains experimental results of Accelerated mortar bar test (AMBT) and mechanical strength (Compressive and Flexure) of OPC mix and Geopolymer mix. Also, these results are discussed and analyzed in this chapter.
- Chapter 5 describes the conclusions drawn after analyzing this study and recommendation for future work.
- Chapter 6 has the references from where we have taken guidance and help to complete our project

CHAPTER 2: Literature Review

2.1 GEOPOLYMER CONCRETE

2.1.1 HISTORY

One of the most extensively utilized materials on the planet is concrete. Researchers are looking for novel alternative materials in response to the rise in environmental concerns. Manufacturing of conventional cement is enormously energy intensive, using polymer-based binder material in civil infrastructure projects could be an alternative in the future. In comparison to traditional concrete with natural coarse aggregates, using RA instead of coarse aggregate in geopolymer concrete from destruction sites offers the possible economic and ecological benefits. This investigation aims:

- To observe the mechanism of ASR in Geopolymer concrete vs ASR in Ordinary Portland cement concrete.
- To Assess mechanical properties prior to alkali exposure and after alkali exposure.
- To Compare behavior of GPC made with various proportions of fly ash and slag, on ASR and mechanical properties

The testing findings show that geopolymer concrete outperforms ordinary concrete in terms of performance. Although geopolymer concrete's compressive and splitting strengths are lower than ordinary concrete, they are well within the acceptable range. According to our findings, geopolymer concrete could be a viable alternative to traditional concrete.

The term "geopolymer" was initially used for defining a class of inorganic binders that had a chemical configuration same as zeolites but non crystalline microstructure. Contrasting traditional OPC, geopolymer concrete don't rely on calcium-silicate-hydrates (CSHs) for strength and matrix development. To produce structural strength, they require on the polycondensation of alumina and silica precursors. The two main geopolymer concrete's components are aluminosilicate source and alkaline solution. For aluminosilicate source, leftovers such as such as GGBFS, fly ash, red mud, silica fumes, rice husk ash, and other alumino-silicate-based materials rich in both aluminium (Al) and silicon (Si) might be employed. Geopolymers differ from other aluminosilicate compounds in several ways (for example, zeolites, glasses and aluminosilicate gels). In comparison to aluminosilicate gel or zeolite synthesis, geopolymerisation produces a higher solid concentration.

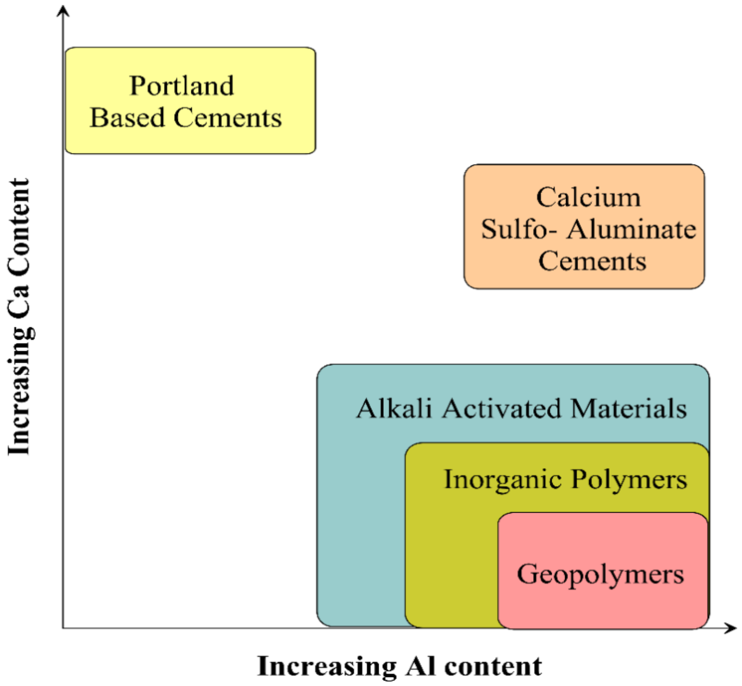


Figure **2-1**.1 Classification of various alkali activated materials. Dark colors resemble to greater concentrations of alkali Adopted from van Deventer et al. (2010)

2.1.2 GEO POLYMERIZATION MECHANISM

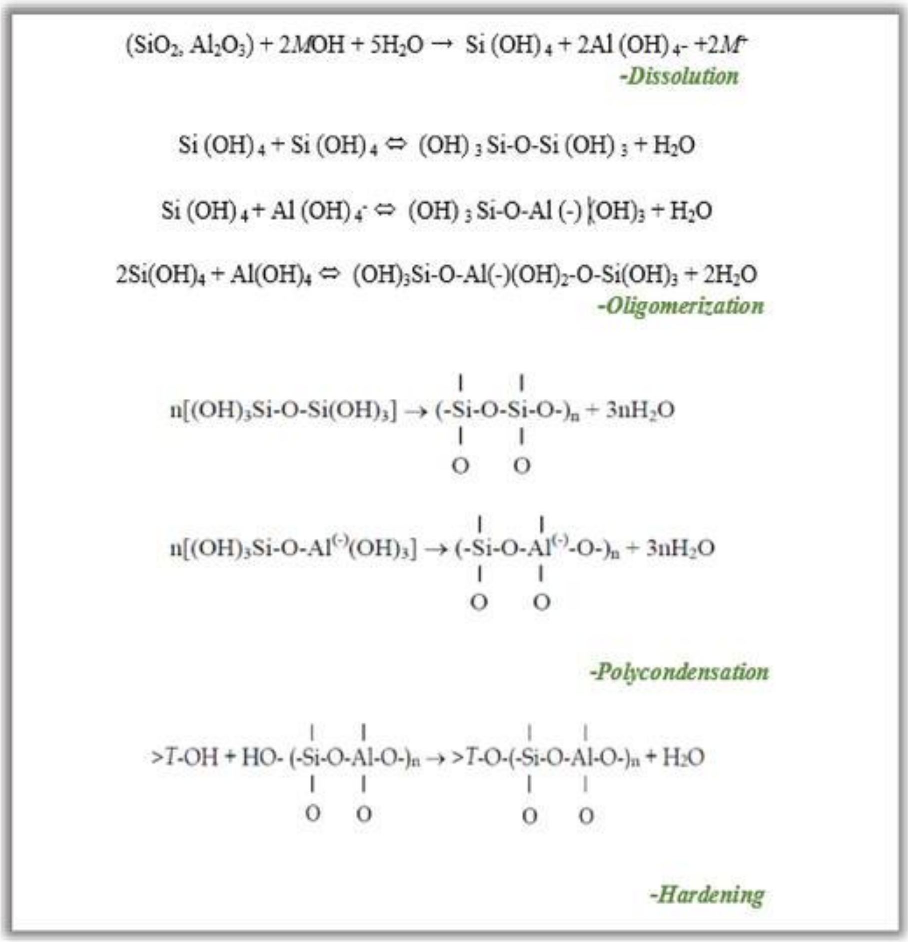
It is regarded as the process of alumino silicates transfer unprocessed material into covalently bonded three dimensional system which consists of [—Si—O—Al—O—]n bonds. This process of geo polymerization forms gooey cementitious slurry which form compact, strong and durable geo polymeric material upon its hardening. Much has been known about geopolymers and their chemistry since the late 1990's and the hard work is continuously going on toreveal several latest scientific features of the aforementioned materials. The information about geopolymers throughout the previous 20 years shows us that the geopolymers are being made by utilizing unprocessed materials which's structure fundamentally contains reactive alumina and silica, for example the solution used for alkali activation (NaOH and Na_2SiO_3 combination) and fly ash.

The first step is association, which involves the binding of water molecules to the siloxane bond (SiOSi) found in the aluminosilicate raw material. There occurs the formation of an intermediate silicon specie. Because of its pentavalent nature, it is extremely reactive. It possesses a trigonal bipyramid structure that is deformed and dissociates quickly.

Step II of the SN2 process is dissociation, in which pentavalent silicon undergoes concerted dissociation and generates silanol (>SiOH) and aluminol (>AlOH) groups. Silanediol $SiO(OH)_2$, silanetriol $SiO(OH)_3$, and silanetetraol $Si(OH)_4$ are formed as a result of these reactions. In aluminosilicate materials, Al oxides are hydrated to create aluminol (>AlOH), which has a minus charge and is written as $Al(OH)_4$. Because it donated just 3 negative charges to the bonding framework instead of 4 silicon atoms, Al^{3+} generated a fourfold coordination structure and carries one negative charge.

The oligomers of silanols and aluminols undergo Auto polycondensation, and oligomers are changed to polymers with water molecules are released, hardening to a dense, robust three dimensional structure of [SiOAlO]n framework.

Figure 2.2 depicts the SN2 mechanism as well as the entire reaction process. The complete representation of silanol and aluminol connections in geopolymerization via SN2 is shown in Figure 2.3.



$$(SiO_2, Al_2O_3) + 2MOH + 5H_2O \rightarrow Si(OH)_4 + 2Al(OH)_4^- + 2M^+$$

-Dissolution

$$Si(OH)_4 + Si(OH)_4 \Leftrightarrow (OH)_3Si\text{-}O\text{-}Si(OH)_3 + H_2O$$

$$Si(OH)_4 + Al(OH)_4^- \Leftrightarrow (OH)_3Si\text{-}O\text{-}Al(-)(OH)_3 + H_2O$$

$$2Si(OH)_4 + Al(OH)_4 \Leftrightarrow (OH)_3Si\text{-}O\text{-}Al(-)(OH)_2\text{-}O\text{-}Si(OH)_3 + 2H_2O$$

-Oligomerization

$$n[(OH)_3Si\text{-}O\text{-}Si(OH)_3] \rightarrow (\text{-}\overset{|}{\underset{\underset{O}{|}}{Si}}\text{-}O\text{-}\overset{|}{\underset{\underset{O}{|}}{Si}}\text{-}O\text{-})_n + 3nH_2O$$

$$n[(OH)_3Si\text{-}O\text{-}Al^{(-)}(OH)_3] \rightarrow (\text{-}\overset{|}{\underset{\underset{O}{|}}{Si}}\text{-}O\text{-}\overset{|}{\underset{\underset{O}{|}}{Al^{(-)}}}\text{-}O\text{-})_n + 3nH_2O$$

-Polycondensation

$$>T\text{-}OH + HO\text{-}(\text{-}\overset{|}{\underset{\underset{O}{|}}{Si}}\text{-}O\text{-}\overset{|}{\underset{\underset{O}{|}}{Al}}\text{-}O\text{-})_n \rightarrow >T\text{-}O\text{-}(\text{-}\overset{|}{\underset{\underset{O}{|}}{Si}}\text{-}O\text{-}\overset{|}{\underset{\underset{O}{|}}{Al}}\text{-}O\text{-})_n + H_2O$$

-Hardening

FIGURE 2-2 REACTION SEQUENCE FOR SN2 MECHANISM

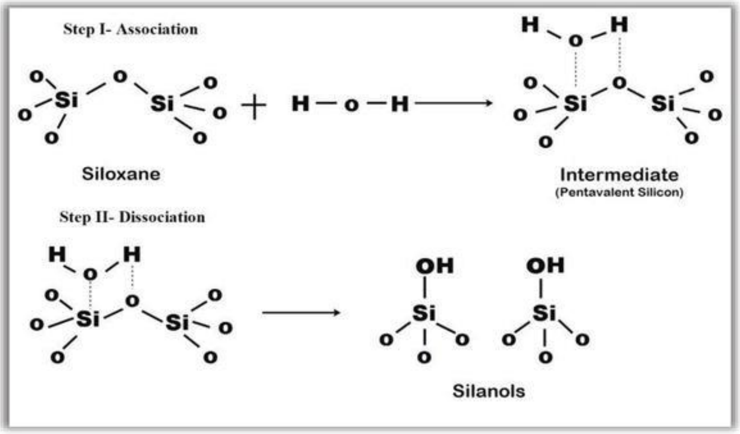


FIGURE 2-3 ILLUSTRATION OF SILANOL AND ALUMINOL LINKAGES IN GEOPOLYMERIZATION

2.1.3 CONSTITUENTS OF GEOPOLYMER BINDER

(a) Fly ash

Rendering to the ACI Committee 116R, we can define fly ash daintily split remainder which we after the burning of crushed or pulverized coal and is carried to the system for materials exclusion from the burning region by flue gases (ACI Committee 232 2004). Fly ash removal is performed using a dust collection system, a mechanical process, or electrostatic precipitators. These particles are characteristically sphere-shaped, finer than lime and OPC, with diameters in the range of 0.3µm - 250µm. The “oxides of silicon (SiO_2)”, “aluminum (Al_2O_3)”, “iron (Fe_2O_3)”, and “calcium (CaO)” make up most of the chemical makeup. Different elements like magnesium, potassium, sodium, titanium, and sulphur are also present, albeit in more negligible amounts. The coal type has a significant influence on the fly ash composition. Sub-bituminous coal and its combustion have more significant calcium and lower iron than fly ash of bituminous coal. Coal's chemical and physical features are affected by the combustion processes utilized, particle size, and the coal source.

Chemical compositions vary widely, indicating that coal utilized in power plants worldwide has a wide range of chemical compositions (Malhotra and Ramezanianpour 1994). Depending on the mineral and chemical composition, fly ash can range in color from brown to dark grey (ACAA 2003). It can also be light to mid-grey in hue, like the cement powder’s color and ordinary fly ash.

Other features of fly ash which are frequently evaluated are fineness, ignition loss (LOI), and homogeneity, in addition to chemical composition. The LOI measures the quantity of ash’s non-combusted carbon.

The fly ash fineness is mainly determined by the conditions of coal crushers and the coal's grinding process. The finer the gradation, the more reactive the ash is and the less carbon it contains. The annual production of fly ash in the United States was at 68 million tonnes in 2001Only 32% of this was employed in a variety of applications, including concrete, structural infill, trash stabilization/solidification, and so on (ACAA 2003). In 2000, Australia produced approximately 12 million tonnes of ash, of which 5.5 million tonnes were used (Heidrich 2002). In 1998, the global yearly production of coal ash was predicted to be around 390 million tonnes. China and India were the primary donors to this sum. Only approximately 14% of the fly ash was used, with the rest is dumped in landfills (Malhotra 1999). The amount of fly ash produced annually in 2010 is expected to be over 780 million tonnes worldwide (Malhotra 2002). Improved concrete durability, reduced energy consumption, reduced greenhouse gas output, reduced amount of fly ash that must be disposed of in landfills, and saving of other natural resources and materials are all significant environmental benefits of using fly ash, especially in concrete manufacturing (ACAA 2003).

Fernández-Jiménez and Palomo (2003) reported that “to achieve optimal binding properties in alkali activation, fly ash should have the following characteristic”:

- “Percentage of unburned particles should be less than 5 %.”
- “Fe_2O_3 content less than equal to 10 %.”
- “CaO content less than equal to 10 %.”
- “Reactive silica content b/w 40-50%. “
- “80-90% fraction of particles lower than 45 μm.”
- “Vitreous phase should be more than 50%. “
- “[SiO_2] reactive/[Al_2O_3] reactive > 1.5 “

Many scholars who studied the durability of geopolymer binder concluded that geopolymer with class F fly ash is often more durable than geopolymer with class C fly ash (Bakharev 2005; Duxson & Provis 2008; Temuujin et al. 2013). Even though class F fly ash has a lower early strength development than class C fly ash, most researchers favored class F fly ash as an aluminosilicate source in geopolymer binders due to its low calcium content and lowered ASR extent. Furthermore, only a few nations have class C fly ash, reducing its significance as an aluminosilicate supply material (Nath 2014; Tennakoon 2016).

We have also selected it for the same reason

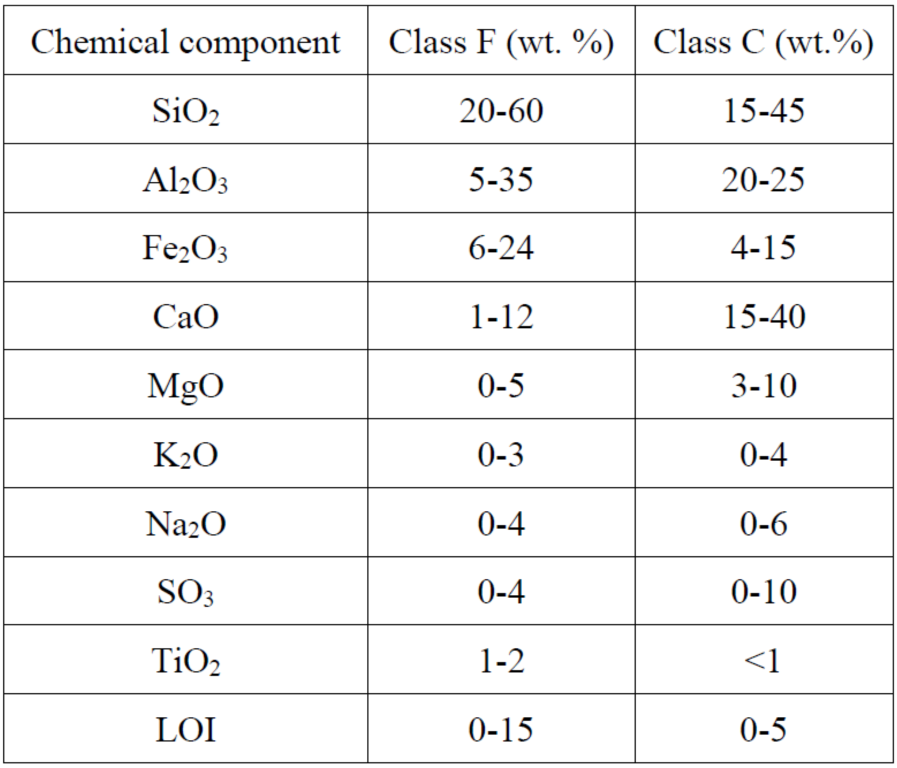
Class C vs. Class F Fly ash:

Early on, Class C fly ashes have a faster rate of reactivity than Class F fly ashes. When it comes to building 28-day strength, some Class C fly ashes are just as good as Portland cement. (9) In the manufacturing of high-strength concrete, both Class F and Class C fly ashes are helpful.

Class F fly ashes are more effective than Class C fly ashes at reducing hydration heat.

All Class F fly ashes, and most Class C fly ashes increase the time it takes for concrete to set when used to replace up to 25% of the Portland cement.

Fly ash, particularly Class F fly ash, is effective in reducing alkali-silica expansion in three ways: 1) it produces a denser, less permeable concrete; 2) it reduces total alkali content by reducing Portland cement, and 3) alkalis react with fly ash instead of reactive silica aggregates when used as a cement replacement. Because of their increased silica content, which can react with alkalis, Class F fly ashes are likely to be more effective than Class C fly ashes. Class C fly ash users should test the long-term volume stability of concrete mixes in the laboratory before using them in the field, with ASTM C441 as a recommended method of testing. [21]



Chemical component	Class F (wt. %)	Class C (wt.%)
SiO_2	20-60	15-45
Al_2O_3	5-35	20-25
Fe_2O_3	6-24	4-15
CaO	1-12	15-40
MgO	0-5	3-10
K_2O	0-3	0-4
Na_2O	0-4	0-6
SO_3	0-4	0-10
TiO_2	1-2	<1
LOI	0-15	0-5

TABLE 1 CHEMICAL COMPOSITION OF FLY ASH

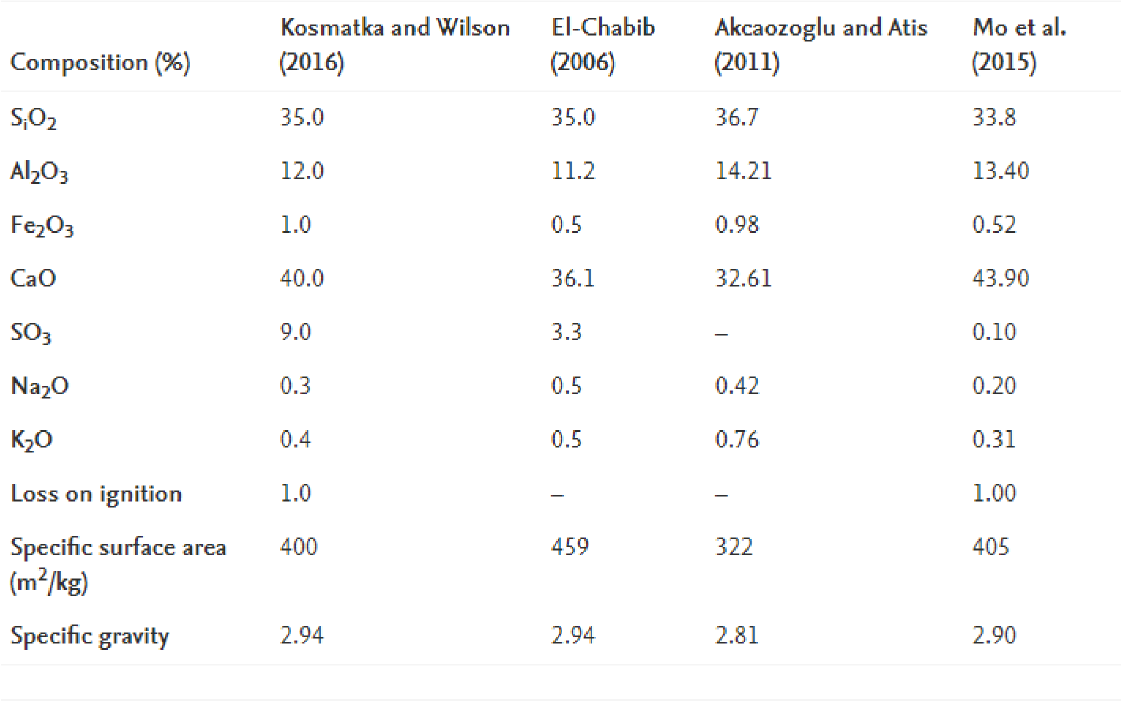
Source: Dinesh Mahanama Habaragamu Arachchige 2018

(b) Slag

The by-product of blast-furnace iron production is GGBFS (ground granulated blast-furnace slag). It's mostly made up of molten calcium silicate and aluminosilicate, which had to be regularly removed from the blast furnace. The chemical compositions of GGBFS, like fly ash, are defined by the raw materials used in the production of iron, while the physical properties are determined by the cooling technique utilized. The molten material is quickly cooled by quenching it in water with a high-pressure water jet to produce amorphous glassy granulated particles (Fig. 11.2) or pelletizing it with a water jet and air mixture to produce spherical glassy pellets. The tiny particles are subsequently ground to a 45-meter diameter and a surface area of 400-600 m2/kg. GGBFS is a hydraulic material that can hydrate and create a hardened composite when exposed to water. Several factors, including chemical composition and glass content, influence the reactivity index of GGBFS, which affects its cementitious performance.

ASTM C989 classifies slag as Grade 80, Grade 100, or Grade 120 based on its increasing level of reactivity, with Grade 120 having the highest reactivity index.

The chemical composition of ground granulated blast furnace slag is shown in the table.



Composition (%)	Kosmatka and Wilson (2016)	El-Chabib (2006)	Akcaozoglu and Atis (2011)	Mo et al. (2015)
S_iO_2	35.0	35.0	36.7	33.8
Al_2O_3	12.0	11.2	14.21	13.40
Fe_2O_3	1.0	0.5	0.98	0.52
CaO	40.0	36.1	32.61	43.90
SO_3	9.0	3.3	–	0.10
Na_2O	0.3	0.5	0.42	0.20
K_2O	0.4	0.5	0.76	0.31
Loss on ignition	1.0	–	–	1.00
Specific surface area (m^2/kg)	400	459	322	405
Specific gravity	2.94	2.94	2.81	2.90

TABLE 2 CHEMICAL COMPOSITION OF SLAG

In conjunction with regular Portland cement and other pozzolanic ingredients, GGBS is utilized to create long-lasting concrete buildings. For its higher concrete durability, GGBS has been widely employed in Europe and increasingly in the United States and Asia (especially in Japan and Singapore), extending the lifespan of structures from fifty to a hundred years.

The manufacturing of quality-improved slag cement, such as Portland Blast furnace cement (PBFC) and high-slag blast-furnace cement (HSBFC), with GGBS content ranging from 30 to 70 percent, and the creation of ready-mixed or site-batched durable concrete are two of the most common uses of GGBS.

Depending on the proportion of GGBS in the cementitious material, concrete formed with GGBS cement sets more slowly than concrete manufactured with conventional Portland cement, but it also gains strength over a longer length of time in manufacturing settings. This reduces the heat of hydration and temperature rises, making it simpler to prevent cold joints, but it may also impair construction timetables, where a quick setting is required.

The use of GGBS minimizes the risk of alkali-silica reaction (ASR) damage, increases resistance to chloride ingress (which lessens the risk of reinforcement corrosion), and increases resistance to sulfate and other chemical attacks.

The use of slag cement reduces the quantity of alkali in the system accessible for reactivity with the aggregate, lowering the risk of ASR. When compared to portland cement, a more significant proportion of the alkalis are bound by the hydration products of slag cement, which implies that the alkali concentration in the concrete pore solution is lowered, lowering the danger of alkali poisoning, reducing risk with reaction with aggregate

Concrete constructed with GGBS cement has better ultimate strength than Portland cement concrete. It contains more strength-enhancing calcium silicate hydrates (CSH) than concrete prepared solely with Portland cement, as well as less free lime, which does not contribute to concrete strength. Concrete built with GGBS gains strength with time and has been proven to quadruple its 28-day strength over a 10- to 12-year timeframe.

The usage of GGBS in concrete is recognized by LEED and others as improving the project's sustainability and will thus contribute to LEED certification. GGBS can be used for superstructure in addition to situations where the concrete is in contact with chlorides and sulfates. This assumes that the extra setup time required for superstructure casting is justified.

(c) Alkali Activator

For geopolymerization, the most common solutions used as an activator are the sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) amalgamation or potassium silicate (K_2SiO_3) and potassium hydroxide (KOH) amalgamation. (Davidovits 2008; Lee & Van Deventer 2007). Since potassium salts are too costly, many investigators prefer solutions based on sodium for alkali activation.

When the alkali activator has soluble silicates, the rate of reaction is more significant. Nonetheless, a greater concentration of Na_2SiO_3 can impede the reaction of polycondensation as the extra ions of silica ($SiO_2/M_2O > 2$; M is Na+ or K+) in the framework can confine the contribution of Al ions to the polymeric reaction. Hydroxyl ion concentration (OH^-) in the system affects ions' initial dissolution rate in the geopolymer. Indeed, it is set up that whenever the concentration of OH^- is greater, many silicates available in the aggregates are disintegrated in the solution, minimizing the aggregate’s internal bond structure effect in silica dissolution. (Álvarez-Ayuso et al. 2008; Davidovits 2008). Van Jaarsveld and Van Deventer concluded in 1999 (who did their study on various categories of alkali hydroxides) that the geopolymerization process is influenced by the type of cations because various Si/Al proportions are experienced when different positive ions are used.

After combining alkali silicate and alkali hydroxide solutions, the best practice is to allow them to settle for a day. Since it is preferred to use powder form instead of solutions in the industry, it is essential to carry out a strategy to consolidate an activator in solid form before starting the extensive geopolymer manufacturing. (Tennakoon 2016).

2.1.4 PROPERTIES OF GEOPOLYMER BINDER

Many parameters affect the geopolymer concrete properties. These include the type and quantity of aluminosilicate source, category, the proportion of alkali activator, the amount of water, conditions in which it is cured, mixing variables, etc.

2.1.4.1 PROPERTIES OF FRESH BINDER:

Since we know that geopolymer binder has significant cohesiveness and viscousness, which reduces its workability, many admixtures like retarders, accelerators, and superplasticizers commonly utilized in OPC do not have that much influence in the case of geopolymer mix. A few scientists expressed that the utilization of admixtures may bring about loss of mechanical properties in geopolymer mix (Chindaprasirt et al., 2007; Hardjito, Djwantoro, et al., 2004). They additionally inferred that an increment in water quantity could increase geopolymer blends workability up to some part without having a critical impact on the structural properties of the geopolymer blends. Also, by using various FA/GGBFS proportions, we can control the set duration of the geopolymer mix. This method was effectively executed by Deb et al. (2014) while originating an ambient cured geopolymer concrete. Hence, it is concluded that the properties of the geopolymer mix could be efficiently controlled by altering blend proportions instead of presenting admixtures.

2.1.4.2 PROPERTIES OF HARDENED BINDER:

1. **Normal Consistency**:

When the GGBS proportion in the mix is increased, the normal consistency value decreases. Fly ash has a particular surface area of 28.07 m2/g, while GGBS has a surface area of 22.73 m2/g. Both materials are non-plastic. Fly ash has a higher specific surface area than other materials. Hence a mix with a higher percentage of fly ash has a higher specific surface area, so it necessitates a greater amount of alkaline solution to lubricate the particle surface, resulting in a higher consistency value.

Furthermore, the consistency values are found to be dependent on the concentration of NaOH solution. As the concentration of the alkali solution rises, the consistency values of the mixes rise as well. The viscosity of NaOH solutions is proportional to their concentration. In nature, a highly viscous solution makes the geopolymer paste plastic, which limits the sinking of the plunger linked to the Vicat device into the paste during testing. As a result, the consistency value rises. In comparison to slag-rich combinations, this impact is more evident in fly ash-rich mixtures. As a result, the normal consistency values of binary blended FA-GGBS geopolymer mixes are chemical composition, source material fineness, and alkaline activator solution concentration.

2. **Setting Time:**

It has been discovered that increasing the concentration of the alkaline activator reduces the setting time. Beyond 8 M concentration, however, no substantial reduction in setting times is observed. Slag activated by sodium hydroxide solutions showed a similar tendency, according to Allahverdi et al. (2010). When the amount of GGBS in the FA-GGBS mix is increased, the setting time is reduced significantly. This pattern clearly shows that slag reacts quickly with NaOH solution at room temperature when compared to fly ash. In an aqueous solution of NaOH, the release of Ca^{2+} ions occurs alongside Si^{4+} and Al^{3+} ions from the slag particles. The pozzolanic reaction and the geopolymerization reaction are aided by a higher calcium content in slag. In combination with geopolymeric reaction products, these extra hydration goods reduce the time it takes for the product to set.

3. Hydration Products, Chemical Bonds and Microstructure:

When activated by an alkali solution, the alumino-silicate component of slag and fly ash undergoes polymerization. Alumino-silicates and calcium compounds are abundant in GGBS. In addition to the geopolymerization process, it goes through a hydration reaction. XRD analysis is used to investigate the reaction chemicals produced by activating fly ash and slag with 8 M NaOH solution over time. The FTIR technique is also used to analyze the evolution of chemical bonds. The microstructures are also investigated using SEM. [20]

The raw materials' XRD patterns differ because slag is exclusively a glassy substance, whereas fly ash contains quartz, hematite, mullite, and corundum peaks. The peaks of mullite and quartz in the virgin fly ash specimen remain unaffected during both the setting times of FA geopolymer. At the set periods of fly ash geopolymer, sodium alumino-silicate (N-A-S) compounds of altisite phase, as well as less intense peaks representing semi-crystalline sodium-calcium alumino-silicate (N-C-A-S) compounds of liottite, hauyne, and franzinite, are observed. In addition, there exist a few peaks of calcium alumino-silicate hydrates (C-A-S-H) and calcium silicate hydrates (C-S-H). These peaks became more prominent as the reaction time lengthened. The XRD micrograph of the GGBS geopolymer differs significantly from that of the fly ash-based geopolymer. It had amorphous X-ray patterns and humps representing calcium-based hydration products and calcium–sodium alumino-silicate compounds. Both the first and final setting phases reveal calcium silicate hydrate and calcium alumino-silicate hydrate. During the last setup period, the intensities of these peaks are more evident. Hauyne, lazurite, liottite, and franzinite are also found as zeolitic hybrid reaction products. The more calcium-based materials used, the faster the paste hardens, resulting in early setting and strength growth in slag-based geopolymers [20]. Zhang et al. (2014), Abdel-Gawwad and Abo-El-Enein (2016), and Murmu and Singh all make similar observations (2014).

4. Chloride Ingress:

Because slag contains calcium components, slag promoted quick setting and early strength increase. Similar features have been reported in previous studies on slag-based geopolymers (Li et al., 2013; Nath and Sarker, 2014; Samantasinghar and Singh, 2018).

The majority of researchers who studied the attack of chloride in GPC indicated that steel corrosion resistance in GPC is comparable to or higher than that of OPC (Ganesan et al., 2015; Ma et al., 2016; Ma et al. 2017). Monticelli et al. 2016; Reddy et al. 2012). Ma et al. (2016) found that slag-based geopolymer has a lower chloride ion diffusion rate than OPC. However, Ganesan et al. (2015) found that fly ash-based geopolymer and OPC had equal diffusion rates. As a result, the chloride diffusion rate is influenced by the microstructure of the geopolymer binder. Reddy et al. (2012) investigated the performance of low calcium fly ash geopolymer concrete in a harsh maritime environment and found that the time it took for cracks to emerge in geopolymer was longer than in OPC. Even though geopolymer has a higher resistance to chloride attack, Monticelli et al. (2016) detected a layer of akageneite on the reinforced bars of geopolymer concrete, which could cause non-uniform corrosion. Furthermore, Kriven et al. (2007) successfully reduced steel corrosion using a metakaolin-based geopolymer coating on steel bars.

5. Alkali aggregate reaction

The alkali-aggregate reaction is the chemical interaction between alkali hydroxides and the aggregate's reactive phases that result in the formation of a hygroscopic gel. Even though the alkali-aggregate gel is not expansive in and of itself, a hydraulic reaction with water (or moisture) can cause the gel to swell, causing significant internal pressures and consequently severe structural damage (Fernandes & Broekmans 2013; Hobbs 1988).

Moreover, the alkali-aggregate reaction (AAR) is discussed in detail in Section 2.3

2.1.5 SOCIO-ECONOMIC AND ENVIRONMENTAL FACTORS

As described in section 2.1.4 above, geopolymer binders are associated with a high level of intrinsic properties compared to those of the OPC. The socio-economic and benefits to the environment of GPC make it a better alternative to OPC.

Usage of by-products is one of the essential parts of geopolymer concrete and can reduce production costs. Duxson et al. (2007) reported that the price of geopolymer is 10 to 30% lower than that of the OPC, even if the catalyst cost is high. On the other hand, the use of by-products on a large scale makes it ideal for the recycling method of industries, such as coal-fired power plants (ash), carbon steel (slugs and snails), mining operations (mine tailings), and so on. (Davidovits 2008). There is also a low carbon footprint and low internal energy compared to OPC, which is classified as a sustainable, eco-friendly building material compared to the OPC (Neves 2016). In addition, it has excellent mechanical properties, as described in Section 2.2.5.3, can bring long-term economic advantages, as they increase the life of the structure and hence reduce the maintenance costs.

In a further expansion of their application, the chemical structure of geopolymer binders, since they can be successfully used in toxic waste management, collects a larger ion, cation, without any leaching of problems (Davidovits 2008). In addition, there has been a sharp increase in the first geopolymer strength, which is necessary for the precast concrete industry (Lloyd & Rangan 2010).

2.1.6 CHALLENGES TO BE ADDRESSED IN APPLICATION OF GEOPOLYMER

Although GPC shows a high level of intrinsic properties and has been associated with many social, economic benefits, there are many challenges limiting things that need to be taken care of before it successfully replaces the OPC belt. The most important reason for the delay in geopolymer uptake is a shortage of information, such as long-term behavior and standards, specifications, rules, Nat 2014).

In addition to the above, other problems need attention. The monitoring of the geopolymer binder chemistry is complex because of the products; the products may have a number of undesirable compounds, such as heavy metal ions that are toxic (Alvarez-Ayuso et al., 2008). Lloyd et al. (2010) reported that the basic nutrients could leach out of the polymer film-based network when it comes in contact with water, which could impact the characteristics of the geopolymer.

The industrial production of geopolymer concrete has been limited to the use of the catalyst in the liquid state, which can lead to risks to health and safety in the preparation, handling, and treatment of a mixture (Davidovits 2008; Nath 2014). In addition, there is a need for heat treatment to achieve better performance is possible by the use of geopolymers for the production, Lloyd, & Rangan 2010), as well as the lack of control over the properties of the fresh concrete due to the absence of contaminants (Wet-in 2014).

2.1.7 ADVANTAGES AND DISADVANTAGES OF GEOPOLYMER CONCRETE

2.1.7.1 ADVANTAGES OF GPC:

This is a product that makes the traditional concrete not all that impressive. Given below are some of the advantages of GPC.

Strength:

It has a high compressive strength than conventional concrete. Also, it hardens rapidly and is cured very quickly, making it an ideal solution for rapid construction.

Geopolymer concrete is characterized by the high magnitude of its tensile strength. It is also less brittle than OPC and can withstand more significant movement.

The very low shrinkage and the creep:

Spasticity can lead to severe and dangerous cracks in the concrete due to drying, the heating of the structure, or even water evaporation. Whereas, Geopolymer concrete does not experience significant shrinkage because it does not hydrated and not as permeable. The creep rate of geopolymer concrete has a very low level. Speaking of creep in concrete terms, it is usually used for concrete is continuously deformed by the constant forces are applied to it.

Resistant to Heat and Cold:

It can withstand temperatures of up to 2200 degrees Fahrenheit and yet stay stable. Excessive heating can weaken the concrete's resilience, causing the layers to peel or break down. It won't happen in GPC unless the temperature reaches beyond 2200 degrees Fahrenheit.

It is resistant to freezing in icy conditions. Even if the holes are tiny, water may nevertheless permeate the hardened concrete. When the temperature dips below zero, water freezes and expands, causing fractures to develop. The geopolymer concrete will not freeze.

Chemical resistance:

It is chemically resistant to a high degree. Geopolymer concrete will be unaffected by acids, hazardous waste, or salt water. Corrosion is not as common in GPM as it is in regular Portland cement.

2.1.7.2 DISADVANTAGES OF GEOPOLYMER CONCRETE

While the geopolymer concrete is a super concrete viable alternative to traditional Portland concrete, there are several disadvantages, such as:

The difficulties in the process of production:

Geopolymer concrete requires special treatment, and it is tough to make. This involves the use of chemicals such as sodium hydroxide, which can be harmful to humans.

The Only Pre-Mix:

Geopolymer concrete can be sold only if a pre-cast or pre-mixed material because of the risks that are associated with the production process.

The complexity of the geopolymerization process

In this area of research, it has proven to be inconclusive and is very stable. There is also a lack of consistency.

2.2 Recycle Aggregate

2.2.1 INTRODUCTION

The construction industry produces a huge amount of waste to be recycled and re-used as a reusable device (remote access) to partially or entirely replace the natural units. Recycling reduces waste and energy consumption and therefore contributes to the sustainable development of the construction industry. In this chapter, the need for recycling and the world's current situation is pointed out. The properties of the RA are discuses. RA has a specific gravity lower than that of the natural materials and a high water absorption rate. A low concrete compressive strength characterizes the RA concrete and flexural strength, a lower e-modulus of rigidity, and reduced strength due to the porous nature of RA and as the old disk and the mortar is placed on the filler surface. The strength and resistance to abrasion and are virtually unaffected. Shrinkage, porosity, and water absorption have been long; it increases with the RA of contents.

2.2.2 CLASSIFICATION

Aggregates from building, demolition, and excavation trash are commonly referred to as RA (CDEW). Broken concrete, bricks, rubble, and mixed demolition debris are the three major types of material recovered from the CDEW, according to Silva et al. (2014), and the composition of the RA is classified into four basic categories: (Silva et al. 2014). The following are the details:

* Recycled Concrete Aggregate (RCA), a type of aggregate made from crushed concrete that may be generated using the software.

* RMA (recycled brick aggregate) refers to rock and waste, such as ceramic, clay brick, and sand-lime bricks.

* MRA (Mixed Recycle Aggregate): An aggregate that primarily comprises the RCA and RMA.

* Demolition and construction CDRA is a construction and demolition waste aggregate or an unidentifiable RA due to a lack of knowledge regarding its composition.

There is also another form of aggregate, such as recovered asphalt and concrete pavement debris (REP), which is derived from granular, bitumen bound mixtures, which is also a common alternative material that can be used in geotechnical environments

2.2.3 PRODUCTION OF RECYCLED AGGREGATE

Recycled crushed concrete (RAC) has been carried out in three stages:

2.2.3.1 EVALUATION OF SOURCE CONCRETE*:*

The first step in the RAC in production is to determine the quality of raw concrete. The properties of concrete, such as strength, durability, and composition, have been examined to make informed decisions about selecting the right concrete source.

2.2.3.2 CRUSHING OF DEMOLISHED CONCRETE:

A simple process involves crushing the concrete up to a specific size and quality (usually 20 mm to 50 mm in size).

2.2.3.3 REMOVAL OF CONTAMINANTS:

Remove dirt and debris, such as rebar, steel, the foundation of materials, equipment, shelves, ground, etc. This can be done using various methods, including screening, air separation, or the use of the electro-magnet, etc. Some of the compounds, depending on the size of the line, can also be treated separately.

2.2.4 APPLICATIONS OF RECYCLED AGGREGATE:

The RA will be used to fund the following initiatives:

- It may be used to build gutters, sidewalks, and other structures.

• Large pieces of crushed aggregate that may be utilized for building revetments and, as a result, are particularly beneficial for soil erosion management.

• Crushed stone and recycled concrete may be utilized as the primary aggregates in concrete.

The manufacturing of RAC also results in the development of various goods such as soil improvement materials, concrete additives, asphalt, crumb, and so on.

2.2.5 ADVANTAGES AND DISADVANTAGES OF RA

Advantages of RA:

- Reduce the amount of natural aggregate in construction so that there is less evacuation of natural resources.
- *When it's cut into smaller pieces, it will absorb large amounts of carbon dioxide. This will reduce the amount of CO2 that is emitted into the atmosphere.
- Reduction in costs, some studies have shown a significant decrease in the construction costs for the use of the RAC.
- It Saves space in landfills, reduces the need for new landfill sites, and saves more costs. Creating more employment opportunities, particularly in the manufacturing industry.

Disadvantages of RA:

- Low concrete quality.
- increase the water absorption capacity in the range of 3% to 9%
- decrease in compressive strength (between 10-30%)
- Reduces the workability of concrete.
- Absence of specifications and standards.

  The lower durability of RAC, however, only a few studies have demonstrated enhanced durability if blend with special materials, such as fly ash.

2.3 ALKALI AGGREGATE REACTION (AAR)

2.3.1 INTRODUCTION

In the 1940s, Thomas Stanton, a mining engineer from the University of California's Department of Highways, was claimed to have a new difficulty with concrete strength, based on fractures and stains surrounded by white efflorescence in the mortar cylinder. He went on to say that it was caused by a reaction between the alkali in the cement and specific types of material (Hobbs 1988). This phenomenon has sparked a lot of interest since it is a declaration of the unexplained fractures noticed in several vital infrastructures, such as dams, bridges, sewers, pumps, and so on (Australia, 2015). As a result of Stanton's studies, the United States Bureau of Reclamation set a restriction of 0.60 percent (by weight) of alkali content in cement used in major building projects (Hobbs 1988). However, under preventive precautions and frequent inspections, the great majority of the structures identified as being alkaline could adequately serve their service life. Hobbs, 1988; Curtis, 2000). HB79 table of documented instances in Australia in 2006 covers dams, bridges, reservoirs, and other big infrastructure (Australia, 2015).

The creation of a hygroscopic gel due to a chemical reaction between the hydroxides of the solution and the reactive sites of aggregate is known as ASR. Even though the gel in alkaline condition, the unit is a hydraulic reaction with water (or the water) in the gel to swell, which can lead to high internal pressure, and, therefore, can lead to severe structural problems (Fernandes & Broekmans 2013; Hobbs, 1988).

2.3.2 TYPE OF AAR

There are two main types of harmful alkali reactions, including the following:

i) Alkali-carbonate reaction (ACR)

An Alkaline carbonate reaction is a process of change, and the first is expected in the 1950s, in Canada, to the degradation of the concrete containing dolomite aggregates.

The alkali in the cement reacts with the dolomite crystals in the aggregate, forming brucite (MgOH)2 and calcite, respectively (CaCO3). Swenson and Gillott first introduced this method in 1964, and it may be expressed as follows:

$$CaMg(CO_3)_2 + 2\ NaOH \longrightarrow Mg(OH)_2 + CaCO_3 + Na_2CO_3$$

Brucite $(MgOH)_{2,}$ which is responsible for the volumetric expansion during the dolomitization of the aggregates by absorption of water.

The alkali carbonate reaction is catalyzed by soluble salts of soda, which are generated by the interaction of Na2CO3 with Ca(OH)2 contained in hardened cement paste (HCP), allowing the process to continue indefinitely, as reported by Fournier and Bérubé (2000) and Bérubé et al. (2005).

$$Na_2CO_3 + Ca(OH)_2 \longrightarrow CaCO_3 + 2\ NaOH$$

The sum of the two before-mentioned reactions, leading to the final taking of brucite, calcium carbonate, can be written as follows:

$$CaMg(CO_3)_2 + Ca(OH)_2 \longrightarrow Mg(OH)_2 + 2\ CaCO_3$$

The reaction between Alkali and the Carbonate is less understood than that of the alkaline and silica reaction. A common constant regeneration of sodium hydroxide (NaOH) is shared between the two reactions in the soluble sodium carbonate or sodium silicate with calcium hydroxide, Ca $(OH)_2$. However, the aggregates and impure dolomite may contain clay particles and minor amounts of pyrite (FeS_2) and organic compounds. Hence, the alkali-silica is hidden by the reaction of an alkali carbonate reaction. Whatever the case, a chemical bond between the ASR and ACR can't be ruled out.

ii) Alkali silica reaction (ASR)

The reaction between silica and alkali, more commonly known as "concrete cancer," is a swelling reaction that is very harmful and occurs over time in concrete between a highly alkaline cement paste and the reactive polymer (i.e., non-crystalline) silica gel, if sufficient moisture is provided, it is present in many of the conventional aggregates.

According to the generally recognized convention, the device can be enlarged by producing a soluble and viscous gel of sodium silicate (Na2SiO3 * nH2O, which has also been termed Na2H2SiO4 • nH2O, N-S-H (sodium silicate hydrate). Being hygroscopic, the gel increases the volume and swells when the water is absorbed, and it exerts an expansive pressure inside the siliceous aggregate, which results in loss of concrete's compressive strength, eventually leading to its destruction.

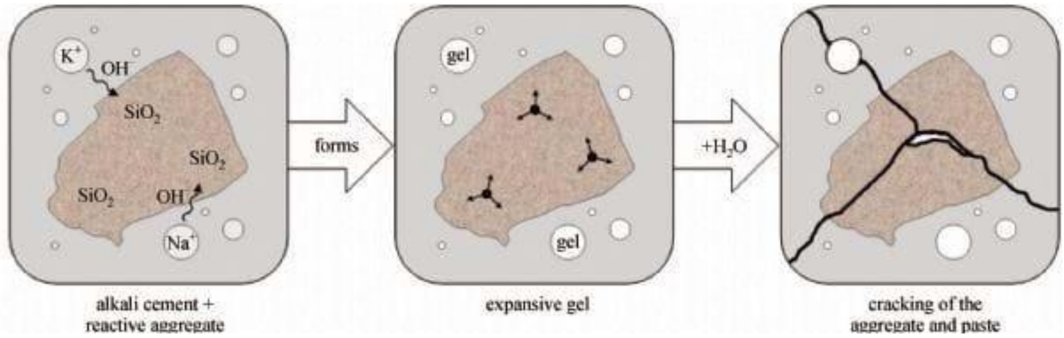


FIGURE 2-4 ALKALI SILICA REACTION - BLOG - MEKA CASE STUDY

ASR can cause significant concrete cracking, leading to serious structural issues that may necessitate removing a structure. Thomas E. Stanton examined the expansion of concrete caused by the reaction between cement and aggregates for the first time in the 1930s in California and published his findings in 1940.

2.3.3 FACTORS AFFECTING ASR

Based on the processes described above, three central components are required for the bad alkali combination reaction to occur:

1. Aggregate (reactive)

2. Loose alkali (Na+ and K+) and OH- content

3. Movement of available moisture

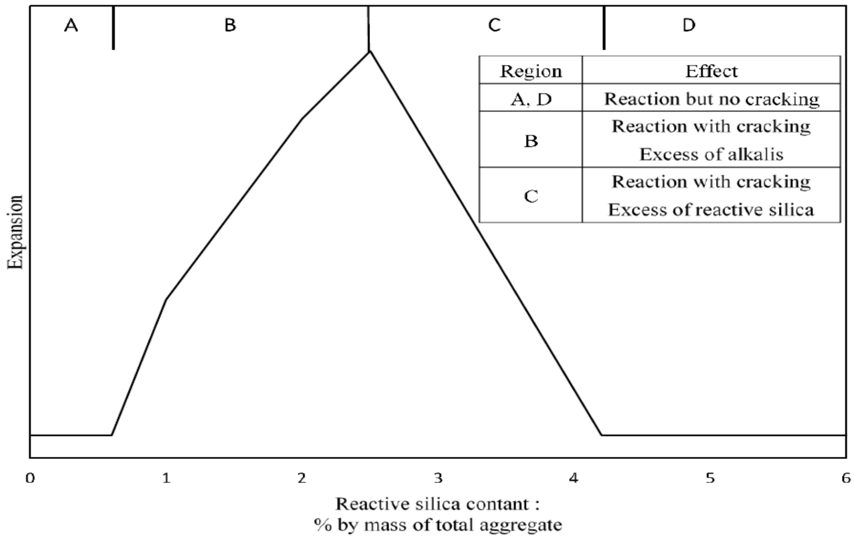
Aside from the three listed above, other factors substantially impact the harmful aggregate alkali reaction that incorporates aluminum and calcium, the paste and its material properties, and conditions regarding the exposure, and so forth. (Hobbs 1988).

2.3.3.1 EFFECT OF AGGREGATES:

The type and degree of reactivity in the system were determined by aggregate type. The degree of microstructural instability in aggregates promotes aggregate reactivity. Crystals (Meta-stable in nature) (ex: tridymite and cristobalite), microcrystalline silica, lattice defects of other crystalline silica (Hob) are the most reactive, followed by amorphous SiO2 (ex: Opal). (Hobbs 1988; Rajabipour et al. 2015). As a result, Swamy (2002) proposed that aggregate ASR potential is determined not by the rock type but by the mineral composition.

The size of a reactive aggregate is pessimistic in behavior on the expansion magnitude, according to Standon (1940), Poyet et al. (2007), and Multon et al. (2008), and the optimum aggregate fraction is dependent on the type of aggregate. However, the mechanism that underlies the behavior mentioned above is still unknown (Rajabipour et al., 2015). Although the damage rating index (DRI) is unaffected by the reactive aggregate size, fracture propagation inside the mortar becomes more sparsely distributed with fine reactive aggregates, according to Sanchez et al. (2016).

According to Hobbs (1988), reactive mineral content likewise follows a pessimum pattern, as illustrated in Figure 2-5. Equilibrium between alkali and reactive silica content in the system explains the pessimum behavior of reactive content (Hobbs 1988; Ichikawa, 2009). In reality, it is apparent that when the reactive content reaches the system's threshold limit, expansion can become zero. The ratio of maximum reactive silica content to equivalent Na_2O content, which varies depending on the reactive aggregate, can be calculated. This ratio is estimated to be around 6 for opaline silica (Hobbs 1988; Rajabipour et al. 2015).



Region	Effect
A, D	Reaction but no cracking
B	Reaction with cracking Excess of alkalis
C	Reaction with cracking Excess of reactive silica

FIGURE 2-5 PESSIMUM BEHAVIOUR OF AGGREGATE (HOBBS 1998)

2.3.3.2 EFFECT OF FREE ALKALI CONTENT:

Alkali plays a crucial part in the alkali-aggregate reaction, according to the reaction processes. Calcium (Ca), in addition to alkalis (Na and K), played a vital role in the response, which resulted in calcium silicate products because of the high calcium content in OPC. Even while calcium-based gel products are necessary to prevent a harmful alkali aggregation reaction in OPC systems, numerous studies show that its swelling capability is lower than that of alkali-based gels, resulting in minor difficulties on an individual basis (Kim, Taehwan & Olek, Jan 2014; Struble & Diamond 1981; Wang & Gillott 1991).

Lithium (Li), like sodium and potassium, is an alkali that is likely to produce harmful ASR expansions. Instead, it has been proved to influence ASR negatively and has been successfully employed to prevent ASR in concrete since McCoy and Caldwell (1951) first reported it in 1951. However, the exact mechanism by which Li salt prevents ASR is unknown (Islam and Ghafoori, 2016, Zapaa-Saweta and Owsiak, 2016, Kawamura and Fuwa, 2003). According to studies, the quantity of Li required to prevent ASR-related discomfort in concrete is a function of the system's sodium equivalent (Na_2Oeq), according to studies (Islam and Ghafoori, 2016). In fact, according to a few studies, aggregate reactivity influences the quantity of Li required to demolish the ASR effect (Zapaa-Saweta and Owsiak, 2016). However, some researchers believe Li has a pessimistic attitude on ASR concrete, which can cause further issues if utilised too much (Kawamura and Fuwa, 2003; Zapaa-Saweta and Owsiak, 2016).

Alkali plays a secondary role in alkali aggregate reaction, keeping a high pH in pore solution, in addition to being a significant ingredient (Rajabipour et al. 2015).

All alkali sources can be divided into two categories;

Internal alkali sources:

If the alkalis in the concrete are supplied by the constituents, those constituents are classified as internal alkali sources. Cement, SCM, aggregates, water, activator, admixtures, and other internal alkali sources include these. It's difficult to regulate the reaction once it's started if the main alkali source is inside. As a result, the most desirable technique of mitigating AAR is to regulate the alkali concentration throughout the design stage (Australia 2015; Farny & Kosmatka 1997; Rajabipour et al. 2015).

External alkali sources:

Agents which are used in de-icing like sea water, waste water, ground water, and other alkali sources that come from the environment outside are classified as external alkali sources. In these types of conditions, cutting off the alkali supply is the best strategy to manage the alkali aggregate reaction (Farny & Kosmatka 1997; Rajabipour et al. 2015). High permeability and crack propagation in structures, according to Grattan-Bellew (1992), may improve the alkali aggregate reaction by increasing the medium's ion transit capabilities.

Moisture movement:

Because ASR gel is hygroscopic, it can swell by chemically retaining certain water molecules. Water is also necessary for the development of internal stress caused by AAR (Australia 2015; Fournier & Bérubé 2000; Rajabipour et al. 2015). In fact, Stark (1991) said that the internal relative humidity should be larger than 80% in order to achieve considerable growth. Even though the swelling phase of the AAR requires a humid environment, Multon and Toutlemonde (2010) found that the gelation phase of the AAR can occur at lower humidity levels. However, many researchers have reported that when ASR gel is exposed to low humidity, its properties change significantly, resulting in lower swelling properties (Fournier & Bérubé 2000; Rajabipour et al. 2015; Struble & Struble & Struble & Struble & Struble & Struble & Struble & Struble & Struble & Struble & Struble & Struble & Struble& Diamond 1981).

2.3.4 IDENTIFICATION OF AAR

AAR recognition consists of multiple phases;

1. **Lab Recognition:**

AAR normally takes an extended time to indicate the early signs. Nevertheless, once start off, it's very difficult to reduce the reaction within the field structures (HB79, 2015; Hobbs 1988). Therefore, the conventional practice is to spot the anticipated AAR within the design phase and take suitable reducing actions. Some established lab methods are given below:

i. **Petrographic analysis:**

Recognition of probably reactive mineral stages in aggregate on the basis of microscopic pictures is termed as petrographic analysis (Farny & Kosmatka 1997; Hobbs 1988). There are two sorts of petrographic analysis supported the specimen preparation (Ahmed and Vander Voort, 2000);

1. Analysis of bulk specimens – surface polished thick samples were examined with a reflected light microscope.

2. Analysis of thin sections – polished thin specimens (thickness< 30µm) were examined with transmitted polarized light microscope.

Analysis of bulk specimens is frequently used to recognize the ASR concrete. However, petrographic analysis does not encompass any quantitative data which significantly limits its use (Hobbs, 1988, Farny and Kosmatka, 1997). But many researchers adapted petrographic analysis along with a quantitative technique like IR spectroscopy, X-ray diffraction, Raman spectroscopy, damage rating index (DRI) etc. (Farny and Kosmatka, 1997).

The major advantage of the petrographic analysis is that less time is required as compare to many similar tests while requiring accurate results. Anyhow, it is also associated with some drawbacks like requiring expert manpower, requiring advanced equipment etc. which may cause larger overheads (Farny & Kosmatka 1997).

ii. Damage rating index (DRI):

DRI was introduced by Grattan-Bellew and his team as a semi-quantitative tool to use along with petrographic analysis in identifying ASR in early 90's (Sanchez et al., 2016). Since then, it has become one of the frequently used semi-quantitative tool accompanied with petrographic analysis due to its simplicity with respect to methodology and technology (Ahmed and Vander Voort, 2000). In DRI, 1cm^2 grid was drawn on the targeted surface and count the damage features of ASR in each grid. Then, number of counts corresponding to each damage feature was multiplied by the weighing factor to balance the relative importance of each feature towards ASR and take the normalized value for 100 cm^2 as DRI in the sample. It should be noted that, ideally at least 200 cm^2 surface should be analyzed to calculate the DRI. (Rivard et al., 2002, Sanchez et al., 2016).

iii. Chemical test:

It is an efficient and straightforward test to spot anticipated ASR on the basis of the dissolution rate of ion from the aggregate (Hobbs 1988). Squashed aggregates were revealed to 1M NaOH solution at 80o C for twenty-four hours prior to measuring the dissolved silica content and therefore the mitigation in alkalinity by titration with acid. The ultimate categorization is predicated on a typical curve established experimentally (ASTM-C289-07 2007). Anyhow, most of the investigators have raised questions on the accuracy of the ultimate results of this test (Farny & Kosmatka 1997; Hobbs 1988). Furthermore, the utilisation of this method is restricted to siliceous aggregate because it examines the Si dissolution rate of the aggregate (Farny & Kosmatka 1997).

iv. Accelerated mortar bar test (AMBT):

It is mostly utilized lab test to spot harmful AAR in concrete (Shon et al. 2002). Quick evaluation method and ease alongside the nearly accurate results making this method more adaptable contrast to other tests. In AMBT, 25mmx25mmx285mm mortar bars are casted using general purpose cement (GPC) and crushed aggregates by keeping the mix ratios laid out in the standard (AS 1141.60.1). Thus, change in length in the mortar bars for initial 21 days is evaluated while disclosing them to 1M NaOH solution at 80°C (Australia 2014).

AMBT includes some approaches to speed up AAR:

- Surface area is increased by using crushed aggregates (Si dissolution rate increases)
- Temperature is increased to 80°C which will increase the rate of reaction
- Submerge in 1M NaOH solution - Contribute Na^+ ions - Keep satisfactory moisture movement - increase the internal pH

Nonetheless, because of the harshness of this method conditions, a number of aggregates having satisfactory field records have also exhibited imprudent expansion with this test. While, the mix design of normal AMBT remained same to clarify the end result which bounded its ability to the categorization of aggregates. Therefore, the recommended standard AMBT as a screening test which implies is HB 79, if the test is not passed by the aggregate, concrete prism test should be accustomed to confirm the reactivity which is a long term test and more reliable. (Australia 2015; Farny & Kosmatka 1997)

v. Concrete prism test (CPT):

CPT is basically originated in Canada for checking the potential alkali carbonate reaction (ACR). This method is very reliable lab test method to spot AAR in concrete due to its higher accuracy. Despite the fact that its testing conditions are very lenient contrast to AMBT, it requires a minimum of 1 year to possess a particular result (AS1141.60.2 2014). Therefore, this method is principally endorsed, if there is no time constraint or a confirmation test to AMBT is required .

2. Field Inspection:

The most reliable way to recognize the AAR in concrete is field conduct data. Nevertheless, prior to assessing aggregates on the basis of its previous performances, the consequences of the subsequent variables ought to be taken under consideration. (Farny & Kosmatka 1997)

- Content of cement in the mix, Content of alkali in the cement and w/c of the concrete ought to be same or lesser than that of the anticipated mix design.
- Age of aimed field concrete should be greater than 15 years
- Expected disclosure conditions ought to be same or slightly harsh contrast to the present conditions
- SCMs effect in the present and suggested structure

Identification of AAR within the field on the basis of the visual symptoms could be a hard task as many signs are similar to different durability problems. Therefore, it's recommended to investigate the field inspection along with lab tests and risk evaluation to assess ASR development (Farny & Kosmatka 1997; Thomas et al. 2011).

Surface Crack propagation:

Irregularly aligned crack generation within the surface which is termed as map cracking (also termed as alligator cracking) is basically the classical crack pattern related to ASR. Despite the fact that on paper, the above mentioned cracking should lay out uniformly in all directions of the structure of concrete, there could likewise be cracks that are directionally oriented due to interior confinement from reinforcement that is provided or external confinements by restrained provided like neighboring constructions or the ground (Thomas et al. 2011). It should be noted that, there can be crack propagations due to the weather and exposure conditions in field structures and thus, requires expertise knowledge on ASR to diagnose ASR in field conditions.

Gel exudation:

Cracks encased by expansive brownish zone is an exemplary indication of ASR in a structure (Thomas et al. 2011). In any case, effloresence as a result of the transmission of water and salt is typically conflated as AAR exudate. Consequently, it is prescribed to hold out a petrographic investigation on the gel exudates to verify AAR.

Surface pop outs:

> Despite being rare, it's possible to look at a surface deterioration because of disunion of little sections of the surface layer of mortar in extreme cases of AAR. This is because of the development of very expansive gel outcomes closed to the surface because of AAR. Freeze-thaw activities along side the existence of irrefutable aggregate categories may aggravate these repercussions (Thomas et al. 2011).

2.3.5 EFFECT OF SLAG CONTENT

Slag content's impact in materials which are alkali activated over the AAR is under light as certain analysts announced uncontrolled expansions in slag-based alkali activated materials. Numerous specialists asserted that slag is the significant calcium source without OPC (portlandite) to support AAR. As slag is a vital constituent inside the mix design which enhances the setting properties and beginning mechanical properties, optimization of slag content is essential to achieve better mix design. (Tennakoon 2016)

2.3.6 EFFECT OF ACTIVATOR

In geopolymer blend, the principle provider of alkali is the activator. Subsequently, the type of activator and its quantity are proving itself as an essential part in the possibility of AAR in alkali activated materials. Indeed, research investigations of You-zhi et al. (2002) inferred that the most extreme impact on AAR is of Na_2SiO_3 which is followed by Na_2CO_3, Na_2SO_4 and NaOH respectively. Moreover, numerous specialists observed a pessimum conduct of silicate modulus (Al-Otaibi 2008; Shi, C et al. 2015) and furthermore the content of alkali over AAR expansion which stressed the significance of optimization of activator quantity to accomplish good mix design.

2.3.7 ROLE OF CALCIUM:

The specific job of calcium in harmful AAR isn't yet characterized. Investigations of (Jewel and Struble) uncovered that calcium rich gel (calcium silicate gel) is exceptionally gooey contrasted with ASR gel and ready to keep up with its structure even at pressures where typal alkali silicates melt. In any case, they also demonstrated that extensive properties of the gel which is calcium based are lower than that gel which is sodium based which means that the production of calcium-based gel can decrease the expansiveness. Consequently, it is feasible to reason that despite the fact that calcium decreases the expensiveness of the gel, it enhances the effective internal pressure development.

IMPORTANCE OF CALCIUM IN ASR GEL FORMATION:

The impact of calcium in the formation of ASR gel was recorded by numerous scientists including Hou et al. (2005), Kim, Taehwan and Olek, Jan (2014) . It was proposed that silica (dissolved) (from the aggregates) will initially react with the accessible calcium to form CSH in light of the fact that CSH has lower saturation energy contrasted with ASR gel. From there on, exceptionally dense CSH act as an inflexible hindrance to separate certain regions in the aggregates, permitting silica ions concentration to increment and arrive at the saturation point of ASR gel.

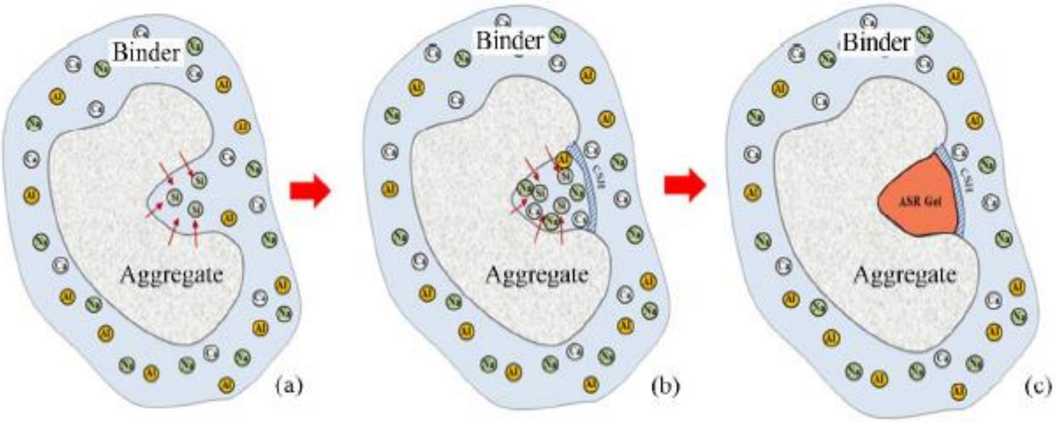


Figure 2-6 : Graphical representation of ASR gel formation mechanism; (a) Si dissolution; (b) Formation of CSH barrier; (c) Formation of ASR gel (after Hou et al. (2004), Kim, Taehwan and Olek, Jan (2014) and Kim, Taehwan and Olek, Jan (2014))

CHAPTER 3: Materials and Methodology

3.1 OVERVIEW

This section contains the particulars of the materials and the test techniques used in this investigation. Being a lethargic response in normal conditions, AAR needs to be sped up in lab scale testings to include perceptible results inside a brief period of time. Accordingly, accelerated mortar bar test based on the ASTM C1260 was used in our study.

GGBFS and class F fly ash combination is utilized as the fundamental aluminosilicate source while as an activator in the geopolymer blends, combination of NaOH and Na_2SiO_3 solutions are utilized. Every parameter in the mix design aside from the GGBFS to fly ash proportion (by weight) remained consistent in the geopolymer blends and for the control test set up, standard AMBT on the basis ASTM C1260 was utilized. Three types of aggregate were utilized which are sand, crushed concrete samples as recycle aggregate, and recycle glass aggregate. Mortar bars were casted and tested as per ASTM C1260 alongside the mortar cubes to survey the strength gain for the early 28 days. Exposure to NaOH solution (with various concentrations which simulate the pH of geopolymer mortar pore solutions) was utilized for testing the dissolution potentials of aggregates. Scanning electron microscopes (SEM) pictures alongside energy dispersive spectroscopy (EDS) were utilized to perceive the advancement of ASR gels and their arrangement over the testing time frame.

3.2 REQUIRED MATERIALS

3.2.1 PORTLAND CEMENT

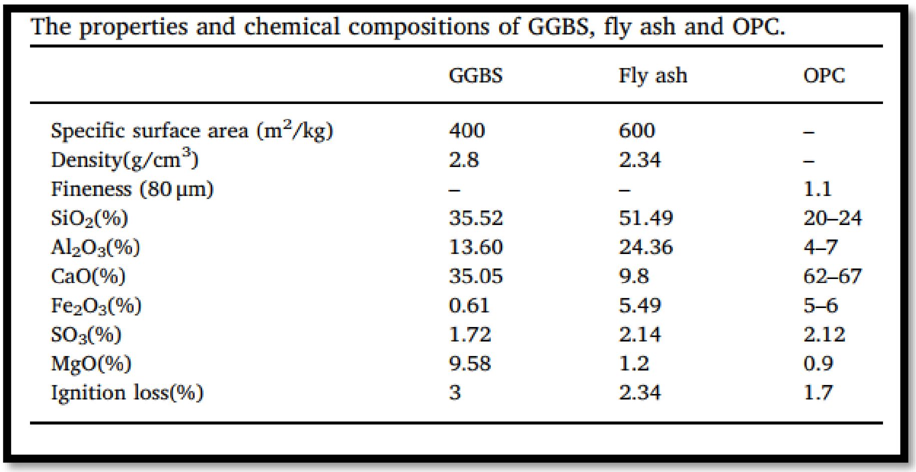
In this study we used Bestway cement.

3.2.2 FLY ASH

Our main binder was class F fly ash which is available in the market. Sieve number 200 passing fly ash is used.

3.2.3 SLAG

Fly ash was partially replaced by GGBFS in this investigation (50% and 25%). The particles passing from 200 sieve was used.



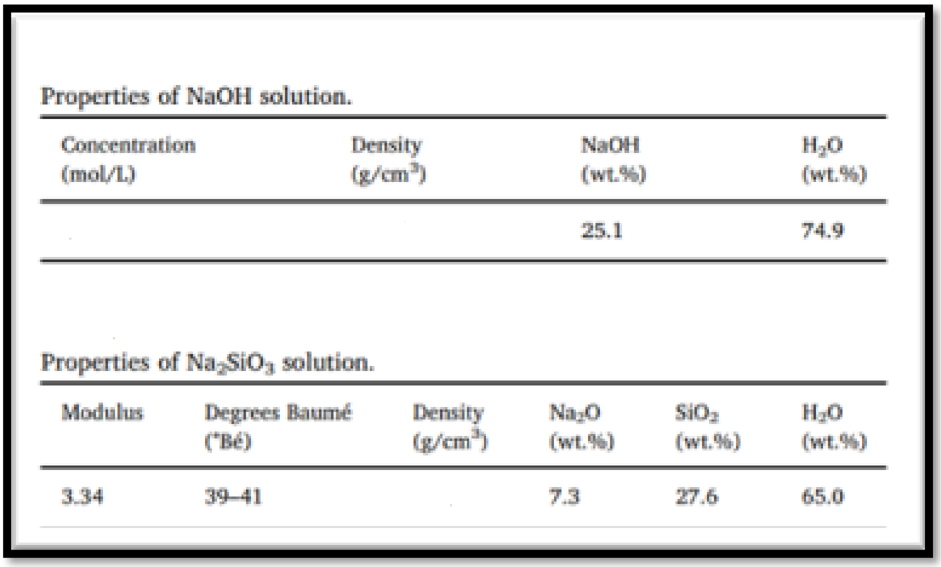
The properties and chemical compositions of GGBS, fly ash and OPC.

	GGBS	Fly ash	OPC
Specific surface area (m^2/kg)	400	600	–
Density(g/cm^3)	2.8	2.34	–
Fineness (80 µm)	–	–	1.1
SiO_2(%)	35.52	51.49	20–24
Al_2O_3(%)	13.60	24.36	4–7
CaO(%)	35.05	9.8	62–67
Fe_2O_3(%)	0.61	5.49	5–6
SO_3(%)	1.72	2.14	2.12
MgO(%)	9.58	1.2	0.9
Ignition loss(%)	3	2.34	1.7

TABLE 3 - OPC, SLAG AND FLY ASH PROPERTIES

3.2.4 ALKALINE ACTIVATOR

Alkaline activator is the combination of NaOH solution and Na_2SiO_3 solution. 12 M concentration NaOH solution was produced by blending 97–98% unadulterated pellets with faucet water. A combination of NaOH and Na_2SiO_3 arrangement with a mass proportion of 1:2.5 was ready at one day before mixing of concrete. The proportion chose was based on the discoveries in literature which gave the best outcomes of geopolymer concrete. The solid NaOH utilized for NaOH solution had an immaculateness of 99%.



Properties of NaOH solution.

Concentration (mol/L)	Density (g/cm^3)	NaOH (wt.%)	H_2O (wt.%)
		25.1	74.9

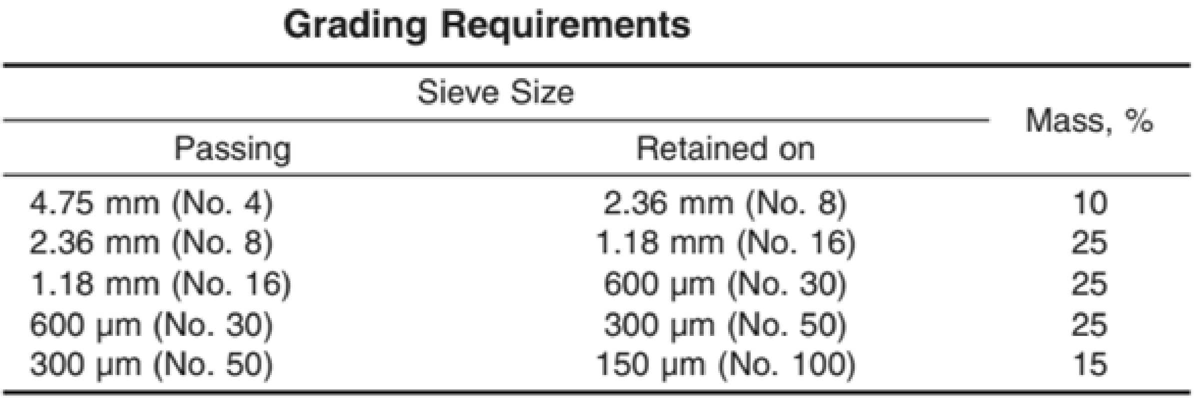
Properties of Na_2SiO_3 solution.

Modulus	Degrees Baumé (°Bé)	Density (g/cm^3)	Na_2O (wt.%)	SiO_2 (wt.%)	H_2O (wt.%)
3.34	39–41		7.3	27.6	65.0

TABLE 4 PROPERTIES OF NaOH AND Na_2SiO_3

3.2.5 SAND

The fine aggregate which we have chosen was locally accessible having fineness modulus of 2.76, also its specific gravity was 2.61, and water retention of 0.8%. As displayed in underneath, the particle size dissemination of fine aggregate could meet the prerequisite specified in ASTM C1260 (Standard Details for Concrete Aggregates for mortar bar experiment).



Grading Requirements

Sieve Size		Mass, %
Passing	Retained on	
4.75 mm (No. 4)	2.36 mm (No. 8)	10
2.36 mm (No. 8)	1.18 mm (No. 16)	25
1.18 mm (No. 16)	600 µm (No. 30)	25
600 µm (No. 30)	300 µm (No. 50)	25
300 µm (No. 50)	150 µm (No. 100)	15

TABLE 5 TABLE 1 FROM ASTM

3.2.6 RECYCLE AGGREGATE

Discarded and detrimental concrete samples from structure engineering lab have been used as the recycle aggregate for our project. Its gradation is similar to sand. (Table 1 from ASTM C1260)

FIGURE 3-1 CRUSHED RA

3.2.7 CRUSHED GLASS AGGREGATE

Coca cola bottles have been washed, crushed and graded according to table 1 ASTM C1260 to use as aggregate in mortar.

FIGURE 3-2 CUSHED GLASS AGGREGATE

3.3 TESTS TO PERFORM

3.3.1 PHYSICAL TESTS ON MATERIALS

3.3.1.1 X-RAY DIFFRACTION (XRD)

An essential utilization of XRD investigation is to recognize materials based on their diffraction pattern, as well as phase identification. XRD additionally yields data on how the genuine structure veers off from the best one, owing to internal stresses and deformities.

It is a non-destructive strategy utilized for:

- Identification of crystalline stages and direction
- Finding properties of structure
- Configuration Variables
- Strain
- Size of grain
- Epitaxy
- Composition of phase
- Orientation which will be preferred
- Determining multi-layers and thin films thickness
- Discovering atomic arrangement

3.3.1.2 SPECIFIC GRAVITY AND BULK DENSITY OF AGGREGATE

For a specified unit volume, weight of the aggregate or mass required to fill a container mass is termed as bulk density.

Bulk Density = Mass/volume

Key Features:

- For a unit volume, its mass is the bulk density.
- Its units are kg/m^3 or lb/ft^3.
- The term volume mentioned in the above definition is that volume which includes the volume of aggregate as well as the volume of voids b/w particles of aggregate.
- Mostly adopted values of bulk density of aggregate for normal-weight concrete is between 1200-1750 kg/m^3 (75-110 lb/ft^3).
- ASTM C 29 (AASHTO T 19) is the standard test for finding the bulk density of aggregates

Ratio of a materials density to the density of water at 73.4°F (23°C) is known as **specific gravity**. Thus, by definition the specific gravity of water will be 1.

Specific Gravity = Mass of the Aggregate / Mass of equal volume of water

Key Features:

- Specific gravity of most aggregates is between 2.4-2.9.
- ASTM C 127(AASHTO) is standard method for coarse aggregates while ASTM C 128 (AASHTO) is specified for fine aggregates.[3]
- oven-dry basis or a saturated surface-dry (SSD) basis can be used to determine specific gravity of an aggregate.

3.3.1.3 FINENESS MODULUS (FM)

Fine aggregate grading affects consistency and finish-ability of concrete. It is an empirical calculation used to support the optimization of a concrete mix design. Fineness modulus offers a way to quantify the aggregate particles mean size in the concrete mix. This can make a connection among grading and consistence as well as the cement quantity or water to fill the voids. A model would be that sand with a high FM will have lower voids between the particles. In this FM will enormously influence how effectively the concrete pours and spreads, as well as its strength and durability once cured.

It is determined by adding cumulative aggregate retained percentage on each sieve from #4 to #100and then dividing it by 100.

$$\text{FM} = \frac{\text{Total Commulative Retained (\%)}}{100}$$

The below given limits can be used for reference:

- 2.2 - 2.6 for fine sand
- 2.6 - 2.9 for medium sand
- 2.9 - 3.2 for coarse sand

To determine FM of fine aggregate we use ASTM C136 method.

3.3.1.4 ABSORPTION AND MOISTURE CONTENT OF AGGREGATES

Aggregates can absorb moisture internally as well as on the exterior surface (surface moisture) as they are porous. These pores are able to hold significant moisture, which may intensely affect a concrete mix. Uses of dry aggregate is efficient in reducing the water quantity within easy reach for hydration; or conversely, in case the aggregate available is very damp, the excess water should be added to a cement mix.

The four moisture states are given below:

- Oven-dry (OD): Removing complete moisture.
- Air-dry (AD): When the surface moisture is removed and the internal pores are partially filled
- Saturated-surface-dry (SSD): Every internal pore is filled while the surface water is removed
- Wet: pores are completely filled with surface film.

Of the previously mentioned 4 dampness conditions, saturated surface dry (SSD), is viewed as the best reference state. It is regarded as an equilibrium state, where the aggregate won't retain or offer water to the cement paste, mimics genuine field conditions very precisely, and used to evaluate bulk specific gravity. Notwithstanding, this dampness state is difficult to get.

To determine w/c of a mix, we determine the amount of water in an aggregate using the following three quantities:

1. **Absorption capacity (*AC*)**: It is the maximum water quantity which is absorbed by the aggregate. For normal weight aggregate, it ranges from 1 - 2 %

$$AC = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100\%$$

2. **Effective Absorption (*EA*)**: The water quantity needed for changing an aggregate state from *AD* to *SSD.*

$$EA = \frac{W_{SSD} - W_{AD}}{W_{SSD}} \times 100\%$$

W_{abs} is the quantity of water soaked up by the aggregate can be calculated from the multiplication of effective absorption (EA) and aggregate's weight, W_{agg}

$$W_{abs} = EA \, . \, W_{agg}$$

3. **Surface Moisture (SM)**: The water quantity in excess of SSD.

$$SM = \frac{W_{wet} - W_{SSD}}{W_{SSD}} \times 100\%$$

By using this SM value, we can calculate the additional water (W_{add}) for the mix

$$W_{add} = SM \, . \, W_{agg}$$

The aggregate's moisture content can be evaluated from:

$$MC = \frac{W_{Stock} - W_{SSD}}{W_{SSD}} \times 100\%$$

For positive value of MC, there will be surface moisture. The negative value of MC shows the potential for absorption. Thus, the water content related with the aggregate is given by:

$$W_{MC} = MC\ .\ W_{agg}$$

3.3.2 ACCELERATED MORTAR BAR TEST (AMBT)

This method is quite possibly the most well-known tests for detecting reactive aggregates. The test is completed by soaking of mortar bars of the dimensions 25 × 25 × 285 mm in solution of NaOH of 1M concentration at 80 °C for 14 days. This test was embraced in 1994 by ASTM. The point of the test is to test the vulnerability of mortar to expansive reactions. (Farny and Kerkhoff, 2007).

Following quite a while of broad overall testing and assessment of the NBRI strategy (Davies and Oberholster, 1987), the test has acquired acknowledgment and has been embraced as ASTM C 1260. Researchers have tracked down that the strategy can distinguish gradually reactive rock categories that already couldn't be recognized by other reactivity tests (Hooton and Rogers, 1989, 1992). This test is an alteration of ASTM C 227, and aggregate and test sample devising are something very similar. The AMBT method subjects the mortar to a cruel stockpiling climate to speed up expansion and prevent alkali leaching. Notwithstanding, the climate additionally creates problematic outcomes in certain aggregates (ASTM, C1260; Ideker et al., 2012).

As a rule, the AMBT is fast, dependable, and can describe the possible reactivity of gradually along with quickly reactive rock categories. In AMBT (ASTM C1260), on the sixteenth day subsequent to, if the mean expansion is exactly 0.10% or lesser than this, the mortar is regarded as nonreactive. On the other hand, if the mean extension is more prominent than 0.10% however beneath 0.20%, the aggregate might be gradually reactive and extra corroborative tests ought to be performed. Provided that the expansion surpasses 0.20%, the aggregate is considered harmfully reactive. Aggregates producing pernicious expansion in the AMBT ought to likewise be assessed following the Concrete Prism Test (CPT) and considering field performance records to confirm the outcomes (ASTM, C1260).

For our project, the samples that were casted for AMBT according to ASTM C1260 were of the size 25 x 25 x 285 mm.

FIGURE 3-3 ABMT SAMPLES 25 X 25 X 285 MM

Apparatus to check the expansion in 7, 14 and 28 day is the length comparator as shown in fig 3.5

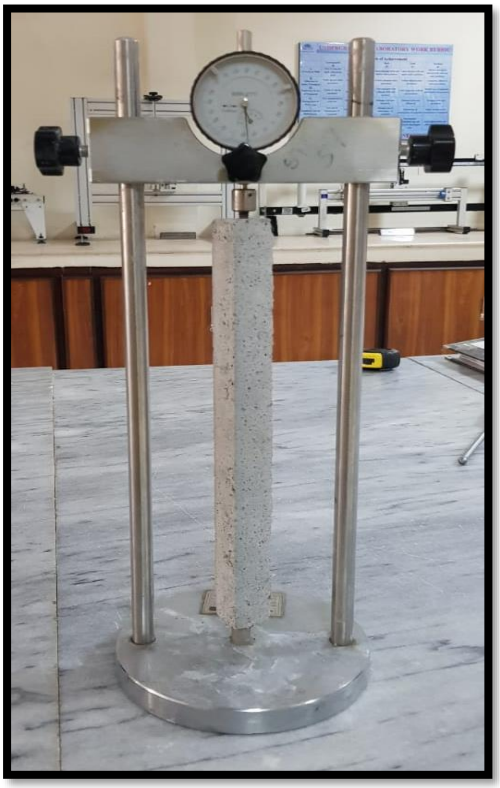


FIGURE 3-4 LENGTH COMPARATOR CALIBRATION **FIGURE 3-5 SAMPLE TESTING ON LENGTH COMPARATOR**

Limitation:

AMBT is quite possibly the most well-known tests to identify reactive aggregate. This test is valuable since it gives results simply in 14 days and it is not difficult to perform. Additionally, in spite of the fact that AMBT is generally performed to recognize reactive aggregate, it has a few restrictions:

- There is field proof for impotence of ASTM C1260 limits (0.10% at 14 days) to identify gradually reactive aggregates.
- The AMBT groups the aggregate however it doesn't consider its pessimal content (pessimal content gives the largest expansion). Due to this reason, a few amalgamations of test aggregate and nonreactive fine materials would be important to be tested.

- The outcomes of AMBT are concerned with the sample dimensions (25 × 25 × 285 mm being common) and it's impossible to extrapolate from this size to the other size. This method is not suitable for permeable flint (chert) aggregates and lightweight aggregates.
- At the same time, in the presence of high alkaline solution (external), not just the high innate alkalis in AAC will be ignored and unfit to show its attributes yet additionally the outer high alkaline solution will react with the AAC (particularly in the beginning phase of hydration), which will significantly affect the outcomes and lead to botches.

3.3.3 MECHANICAL TESTS

3.3.3.1 COMPRESSIVE STRENGTH

The mortar's compressive strength is calculated by using 2 x 2 x 2 in or 50 x 50 x 50 mm cubes according to the standard method for compressive strength specified by ASTM C109 / C109M for mortars. Cement and sand when mixed with water, it forms mortar.

The mortar samples were prepared according to 1 : 2.25. Where cement is taken as one part and aggregate is taken as 2.25 parts by mass. The samples were compacted in two layers using tamping method. The samples were cured for 24 hours in the molds and after demolding it was submerged in water till the test date.

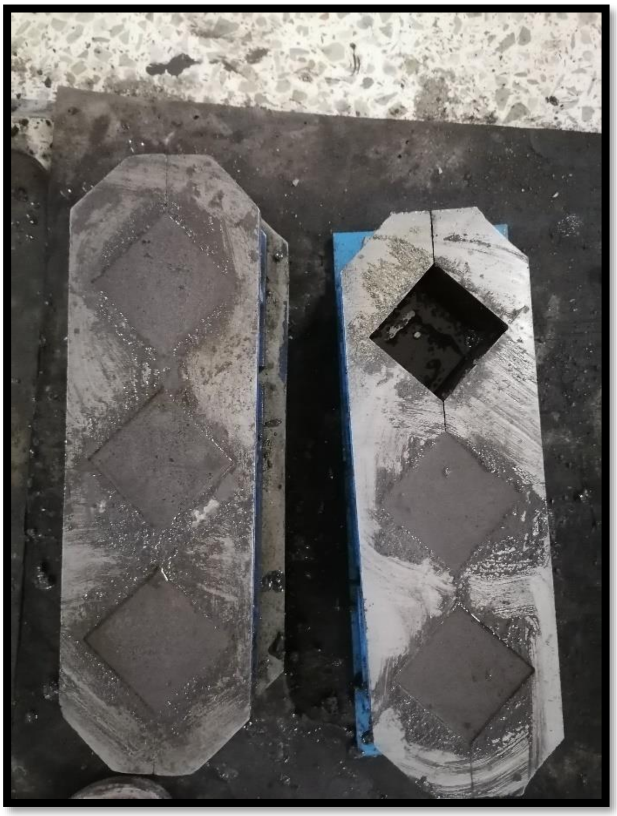


FIGURE 3-6 CUBES FOR COMPRESSION TESTING

The apparatus used for testing was **ADR Touch Control PRO 250/25 Auto Cement Machine** which is shown in fig below

FIGURE 3-7 COMPRESSION AND FLEXURE TESTING MACHINE

This test technique gives a method for evaluating the compressive strength of water-based cement and different mortars and upshots might be utilized to decide conformance with specifications. Additionally, this test strategy is referred by various different specifications and methods. Alert should be practiced in utilizing the upshots of this method to anticipate the concrete strength.

3.3.3.2 FLEXURAL STRENGTH

Flexure strength (often termed as rupture modulus) is the measure of tensile strength in bending. Its test is performed on a 40 x 40 x 160 mm mortar beam. The test is performed by using center point loading method on the beam till the beam fails.

The mortar samples were prepared according to 1 : 2.25. Where cement is taken as one part and aggregate is taken as 2.25 parts by mass. The samples were compacted in two layers using tamping method. The samples were cured for 24 hours in the molds and after demolding it was submerged in water till the test date.

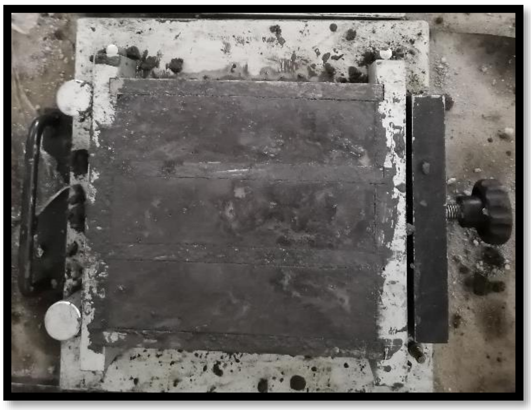


FIGURE 3-8 SAMPLES FOR FLEXURE TEST

The same apparatus used for testing **ADR Touch Control PRO 250/25 Auto Cement Machine** which is shown in fig.

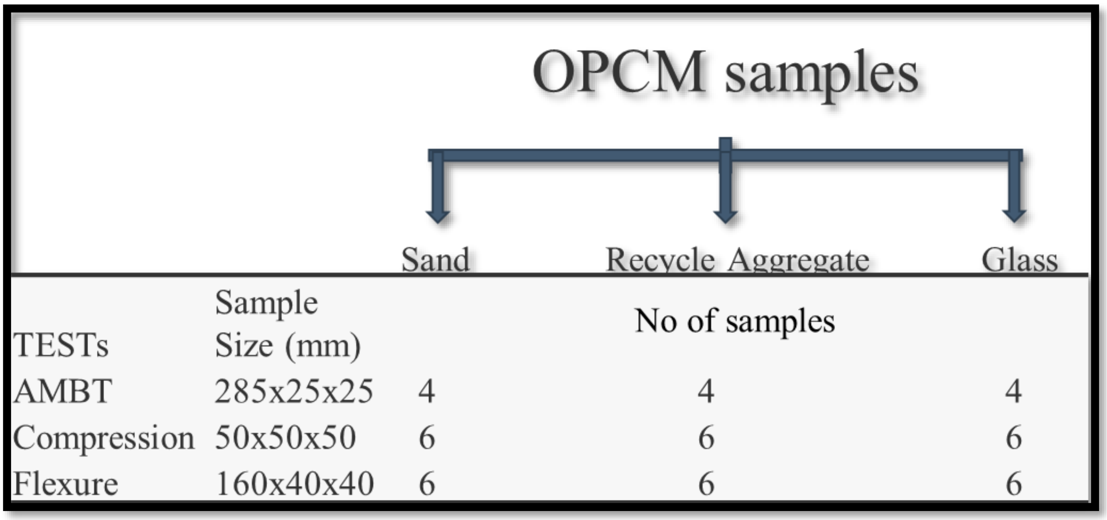
FIGURE 3-9 COMPRESSION AND FLEXURE TESTING MACHINE

3.4 SAMPLES TO CAST

In this study the 48 AMBT samples, 72 samples for compression and 72 samples for flexure were used.

3.4.1 OPC MORTAR SAMPLES

In this study three types of aggregates were used with OPC (sand, RA and glass), and with each aggregate type mix specified number of samples were cast as shown in the table.



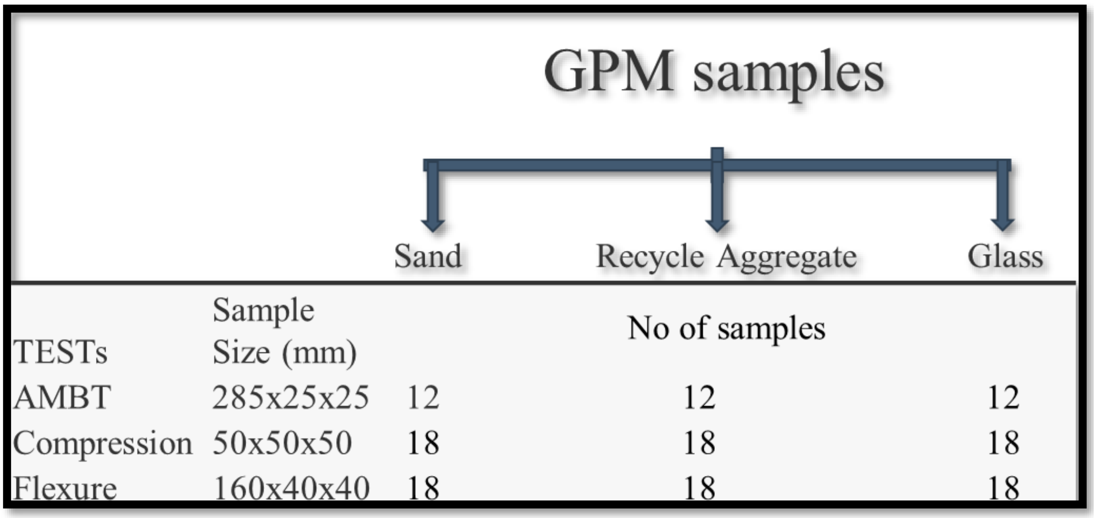
OPCM samples

		Sand	Recycle Aggregate	Glass
TESTs	Sample Size (mm)	No of samples		
AMBT	285x25x25	4	4	4
Compression	50x50x50	6	6	6
Flexure	160x40x40	6	6	6

FIGURE 3-10 TOTAL OPC SAMPLES

3.4.2 GEOPOLYMER MORTAR SAMPLES

Similarly, in GPM same three types of aggregates were used. Total GPM samples are shown in below table.



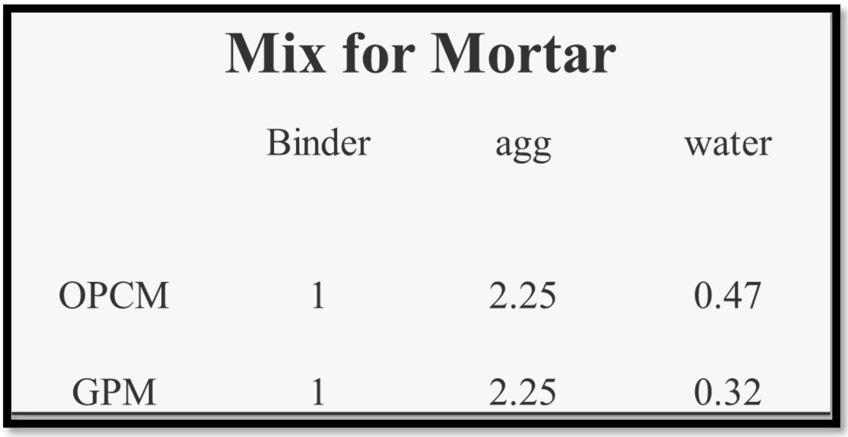
GPM samples

		Sand	Recycle Aggregate	Glass
TESTs	Sample Size (mm)	No of samples		
AMBT	285x25x25	12	12	12
Compression	50x50x50	18	18	18
Flexure	160x40x40	18	18	18

FIGURE 3-11 TOTAL GP SAMPLES

3.5 MIX PROPORTION

The mix design utilized in the study was taken from ASTM C 1260 which is shown in table below.



Mix for Mortar

	Binder	agg	water
OPCM	1	2.25	0.47
GPM	1	2.25	0.32

FIGURE 3-12 MIX PROPORTION

3.6 EXPERIMENTAL PROCEDURE

Step-1: After determining the required total number of samples to cast, the first step is to calculate the amount of each material (sand, RA, glass, OPC, fly ash, slag, activator and water) using the mix design. The excel calculation for OPC mix is shown in the table.

OPC Simple Agg			**all values in kg**			
-		**%OPC**	**OPC**	**F.agg**	**C.agg**	**Water**
SO100	**AMBT**	**100**	0.351	0.765	0.000	0.165
-	**STT**	**100**	1.008	2.198	0.000	0.474
	CCT	**100**	0.677	1.475	0.000	0.318
	Total		2.036	4.438	0.000	0.957
OPC Glass Agg			all values in kg			
		%OPC	**OPC**	**F.agg**	**C.agg**	**Water**
GO100	**AMBT**	**100**	0.263	0.573	0.000	0.124
	CPT	**100**	0.756	1.648	0.000	0.355
	CCT	**100**	0.554	1.207	0.000	0.260
	Total		1.573	3.429	0.000	0.739
-						
OPC Recycle agg			all values in kg			
-		**%OPC**	**OPC**	**F.agg**	**C.agg**	**Water**
RO100	**AMBT**	**100**	0.263	0.573	0.000	0.124
-	**CPT**	**100**	0.756	1.648	0.000	0.355
-	**CCT**	**100**	0.554	1.207	0.000	0.260
-	**Total**		1.573	3.429	0.000	0.739

TABLE 6 CALCULATION FOR OPC MIX

Step-2: After calculating the total amount of materials used the next thing is to buy these materials. This is explained in section 3.2. Now, the physical test is performed on the materials.

Step-3: Preparation of materials is the 3rd step. Crushing and sieving of aggregate weighting the materials according to the mix ratio.

FIGURE 3-13 CRUSHING AND SIEVING

Step-4: Materials are prepared and ready to mix. So, this step involves casting of materials. For mixing we used the standard method of casting ASTM C 305. After casting of mortar, the next step is to fill the molds as shown.

FIGURE 3-14 ALL SAMPLES

Step-5: After curing for 1 day, specimens were placed in 1M NaOH solution at 80°C temperature for 28 Days. All AMBT samples and half of flexure and compression samples are place in the solution for alkali exposure.

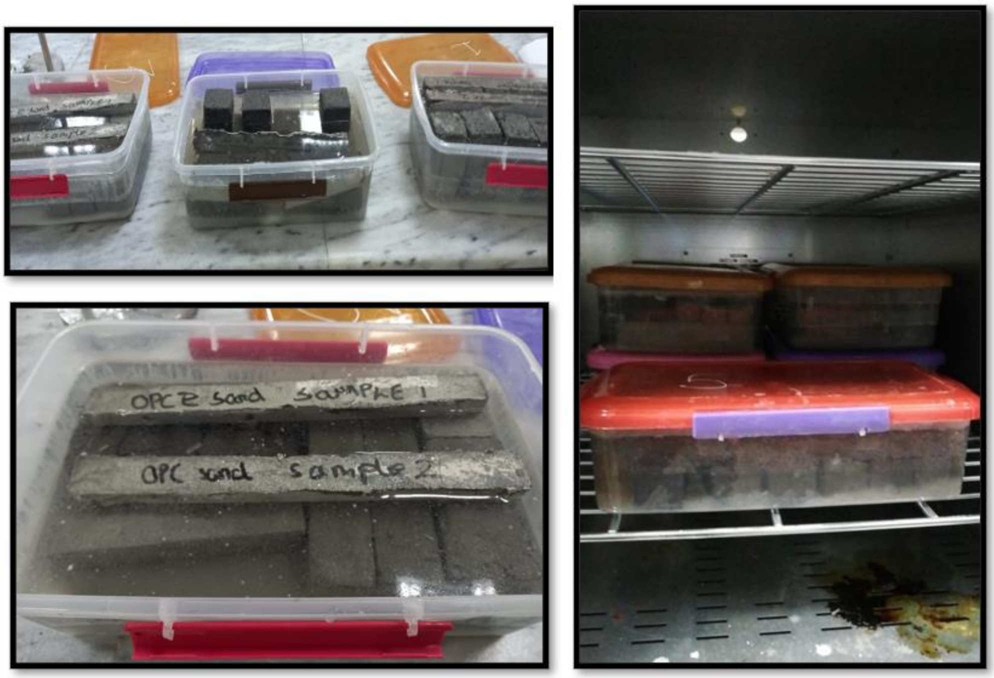


FIGURE 3-15 ALKALI EXPOSURE

Step-6: The AMBT samples placed in the solution are tested at 7-day, 14 day and 28 day using length comparator.

FIGURE 3-16 LENGTH COMPARATOR

Step-7: At 28-day, compression and flexure tests are performed along with the AMBT test as discusses in section 3.3.3.

Step-8: this step involves tabulating of data acquired from experiment and discussion on these results which is detailed in chapter 4.

Step-9: the last step is concluding the results which is explained in chapter 5

CHAPTER 4: Results and Discussion

OVERVIEW

Chapter 4 presents the experimental results of the material testing on cement, sand, fly ash, slag, and recycled aggregate. This chapter contains detailed overview of experimental results of the accelerated mortar bar test (AMBT) and mechanical strength (Compressive and Flexure) of OPC mix and geopolymer mix.

MATERIAL TESTING

Our research materials are Type I OPC, Fly ash class F, ground granulated blast furnace slag, sand, recycled aggregate, and glass aggregate. Properties of these materials through physical testing like density, absorption, moisture content tests are also done.

CEMENT PROPERTIES

Properties of OPC Type I given by the manufacturer of the Bestway cement are given below.

Cement Properties	
Specific Gravity	3.14
Initial Setting (min)	35
Final Setting (min)	135

Table 4.1 Cement Properties

FLY ASH AND SLAG PROPERTIES

Fly Ash Class F was used due to its low calcium content. The following are its properties.

Fly Ash Class F	
SiO_2 plus Al_2O_3 plus Fe_2O_3, min	70 %
SO3 Max	5 %
Moisture content Max	3 %
Loss on ignition Max	6 %

Table 4.2 Fly Ash Properties

Ground Granulated Blast Furnace Slag was used as a secondary binder to study the strength properties in the Geopolymer. A passing of sieve # 200 was used for the study.

Properties of Slag	
Specific gravity	2.48
Compacted Unit weight kg/m3	1315
Absorption %	4%

Table 4.3 Slag Properties

SAND PROPERTIES

Sand Properties	
Median Size, D50 (mm)	0.62
Specific Gravity g/cm3	2.67
Water Absorption	1.60%

Table 4.4 Sand Properties

RECYCLE AGGREGATE PROPERTIES

Properties of Recycled Aggregate obtained from previous concrete samples are given below.

RECYCLE AGGREGATE PROPERTIES	
Fineness Modulus	3.10
Specific Gravity g/cm3	2.49
Water Absorption	2.71%

Table 4.5 Aggregate Properties

ACCELERATED MORTAR BAR TEST

The Geopolymer samples were casted in molds and then wrapped in cling film. Then those molds were placed in the oven to cure at 75 ^{o} C for a period of 18 hours. Then those samples were de-molded and placed in a solution at 80 ^{o} C temperature to accelerate the ASR reaction. The readings of expansion from the length comparator were taken at 7-day, 14-day, and 28-day periods. According to ASTM C 1260 the AMBT results are to be compared to the limit provided in the standard which is 0.1% for 14 days in solution at 80^{o}C temperature. The aggregate samples are considered unreactive if its expansion values are below 0.1%, and if the expansion value is over 0.1% at 14 days and between 0.2% at 28 days then the aggregate is slowly reactive. On the other hand, if the expansion at 14 days is more than 0.1% and more than 0.2% at 28 days, the aggregate is highly reactive. The results of AMBT are discussed in detail below.

EXPANSION RESULTS

1) MIX WITH SAND AS AN AGGREGATE

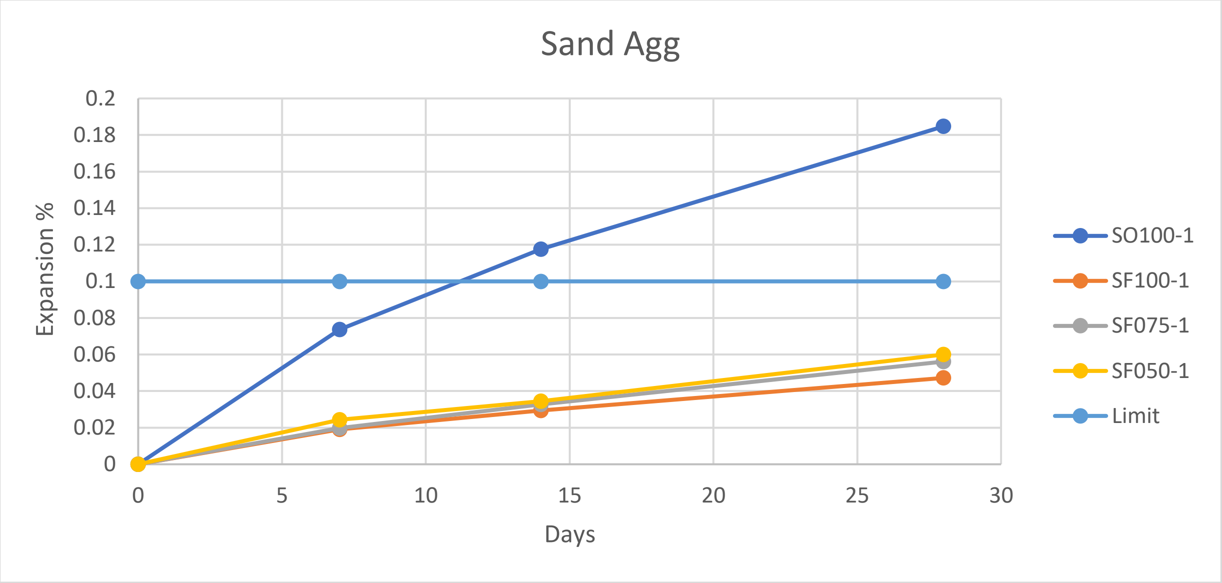
In this study, we used sand as the natural aggregate. A passing of sieve # 4 was used in the study. Three different slags and fly ash ratios were used in the geopolymer mix, along with three kinds of aggregate. 100% fly ash mix, 75% fly ash and 25% slag mix, and 50-50% fly ash and slag mix along with sand as natural aggregate were used to cast mortar bars. The expansion values measured at 7 days, 14 days and 28 days are given in Table 4.6.

Graph 4.1 shows the expansion of all the mortar bars with sand as the aggregate. Here an expansion of 0.1% expansion limit as defined by the ASTM C1260 is marked for better analysis of data.

According to the literature, the geopolymer concrete shows a much small expansion compared to the OPC mix.

Sample	7 Days Expansion	14 Days Expansion	28 Days Expansion
SO100	0.210	0.335	0.52
SF100	0.055	0.084	0.135
SF075	0.057	0.094	0.160
SF050	0.069	0.099	0.171

Table 4.6 Expansion of mortar bars (mm)



Graph 4.1 Expansion of Mortar bars with Sand as an Aggregate (%)

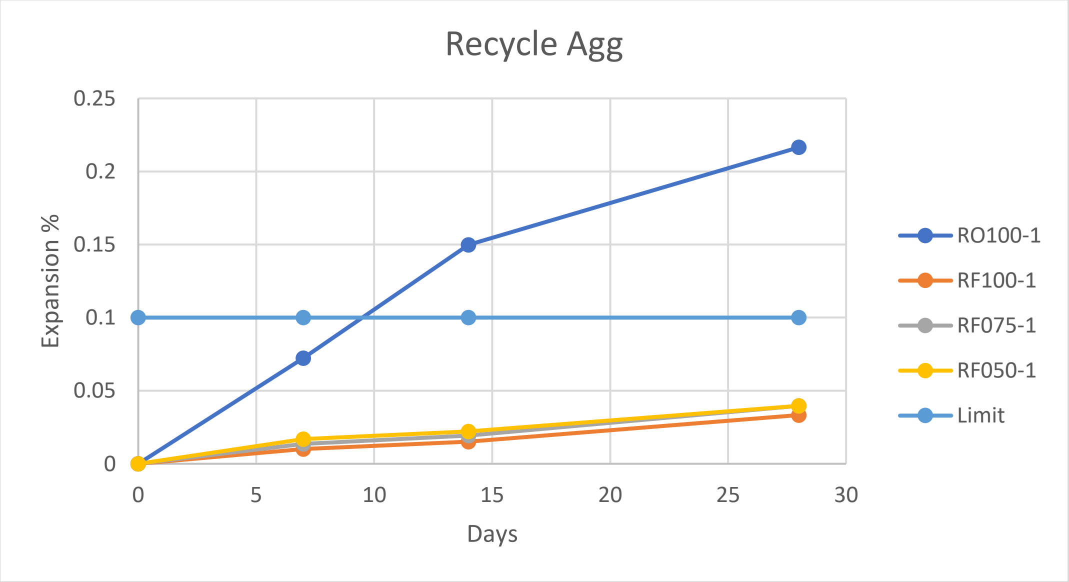
Table 4.6 presents the expansion characteristics of mortar bars cast with OPC and geopolymer mortar with natural Aggregate over 28 days. The expansion values are taken at 7, 14, and 28 days. Here the OPC mix shows expansion after 14 days beyond the limit of 0.1%. The graph shows the expansion of 100% fly ash mix with Sand for 28 days in solution at 80 ° C temperature. The results show that the expansion is under 0.1% even after 28 days of alkali exposure. The expansion of 75% Fly Ash and 25% Slag mix with Sand is under 0.1% The expansion of 50% Fly Ash and 50% Slag mix with Sand is under 0.1% even after 28 days of alkali exposure. This result is as expected due to the chemistry of the mortars present. In the ordinary Portland cement the ASR Reaction is seen due to the presence of sand as an aggregate. The results show that the sand used here is reactive and in Normal Portland cement ASR reaction is seen but when the same aggregate is used in the Geopolymer mortar the ASR is absent this may be due to two factors the first is that due to the lack of calcium present in the fly ash class F the ASR gel cannot complete its reaction cycle thus leading to low ASR gel being formed. This can be further supported by the fact that as the slag concentration is increased the calcium content increases thus leading to a higher value of ASR compared to the 100% fly ash Mortar.

2) MIX WITH RECYCLE AGGREGATE

The mix formulation for recycle aggregate was the same as for sand. Recycled aggregate used was crushed discarded and detrimental lab samples. 100% fly ash mix, 75% fly ash and 25% slag mix, and 50-50% fly ash and slag mix along with recycled aggregate were used to cast mortar bars. The expansion values measured at 7 days, 14 days and 28 days are given in Table 4.7 Graph 4.2 shows the expansion in % and the ASTM C1260 limit.

Sample	**7 DAYS Expansion**	**14 DAYS Expansion**	**28 DAYS Expansion**
RO100	0.206	0.427	0.617
RF100	0.029	0.043	0.095
RF075	0.039	0.055	0.113
RF050	0.048	0.063	0.113

Table 4.7 Expansion values for mortar bar with recycled aggregate (mm)



Graph 4.2 Expansion of mortar bar with Recycled Aggregate (%)

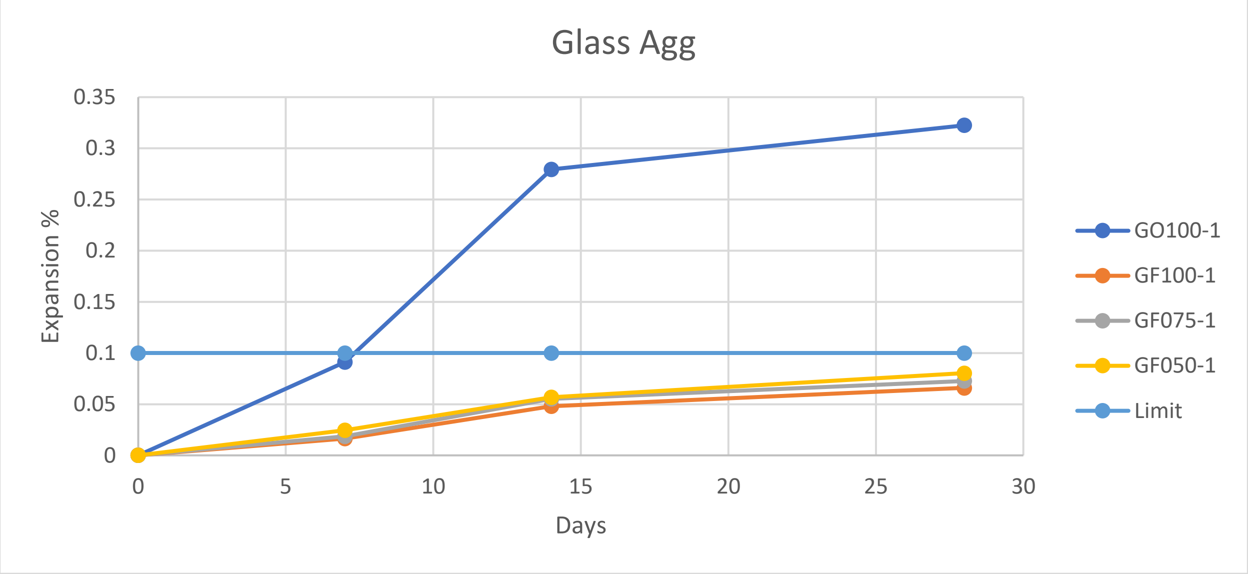
The graph shows the expansion characteristics of mortar bars cast with OPC and Recycled Aggregate over 28 days. The expansion values are over 0.2% after 28 days in solution. This shows that the recycled Aggregate is more reactive than the Sand used in the OPC mix with natural Aggregate. The mortar bars with 100% Fly Ash and recycled aggregate mortar had expansion under 0.1% even after 28 days of alkali exposure. In the OPC mix, the RA shows more expansion than Sand. In this case, the expansion of the mix with RA is less than that of the sand mix. The expansion of 75% Fly Ash and 25% Slag mix with Sand had an expansion of under 0.1% even after 28 days of alkali exposure. By observing the graphs, it can be seen that with the increase in the slag content, the expansion increases due to the increase in calcium content in the mix, as calcium helps with the making of the ASR gel. The expansion of 50% Fly Ash and 50% Slag mix with Sand is under 0.1%. Here again a similar trend is seen as in the sand aggregate, but the values of the Expansion are higher than that of the sand aggregate. Here as recycled aggregate was used the cement in the mortar supplied the ASR with the calcium it needed thus helping the ASR cycle to be completed and ultimately giving a higher expansion percentage compared to the previous aggregate type. Furter I may be noted that even though the general expansion values are higher than before but still the geopolymer mortar did not show an expansion on more than 0.1% since the conc of cement was far less than the geopolymer itself.

3) MIX WITH GLASS

The crushed glass aggregate is used as a fine aggregate in the OPCM mix. As glass is highly reactive aggregate, thus it is used with these formulations to confirm ASR development. So, the expansion was much higher as expected.

Sample	7 DAYS Expansion	14 DAYS Expansion	28 DAYS Expansion
GO100-1	0.26	0.796	0.919
GF100-1	0.047	0.137	0.188
GF075-1	0.053	0.157	0.207
GF050-1	0.07	0.162	0.229

Table 4.8 Expansion values of mortar bar with Glass as Aggregate



Graph 4.3 Expansion of mortar bar with Glass as Aggregate (%)

Table 4.8 presents the expansion characteristics of mortar bars cast with OPC and Geopolymer with glass aggregate mortar. As Glass is highly reactive and so the expansion value is much larger than the 0.1% limit. Even the mix with OPC and Glass shows expansion after seven days beyond the limit showing that Glass undergoes alkali-silica reaction quickly.

In this study, we used the crushed soda bottles as the reactive Aggregate. The significance of this type of Aggregate is mainly due to its 100% silica content which will help us understand the ASR properties of the mortars.

The expansion of 100% fly ash mix with glass aggregate is significantly high, but the GPM samples showed small expansion even with reactive Aggregate. The results show that the expansion is under 0.1% even with Glass after 28 days of alkali exposure. The graph shows the expansion of 75% Fly Ash and 25% Slag mix with Glass is under 0.1%. The expansion of 50% Fly Ash and 50% Slag mix with Glass is under 0.1%. The graphs show that with an increase in the slag content, the expansion value increases.

Highest expansion of all the aggregate types in the glass aggregate was observed due to 100% silica content which is reactive. In the previous aggregate, quantity and quality of reactive silica content of the mix was different, but by providing a 100% silica aggregate, the alkali silica reaction progressed. Thus the behavior of geopolymer mortar formulations against ASR were well understood. It was found that that even though the quantity of reactive silica was large, the expansion of the geopolymer mortar bars did not exceed the 0.1% expansion limit at 14 days. This conclusion is significant to state that all the geopolymer formulations used in this resisted ASR. It is further discussed in detail in the conclusion of this report.

MECHANICAL STRENGTH

Mechanical strength tests were also conducted on the given mix mortar formulations. Two types of tests were shown.

- Compressive strength test
- Flexure strength test

The tests were done using a Double chamber Universal testing machine. The sample dimension and number were as follows:

Test Type	Sample Size (mm)	No of samples		
Compression	50x50x50	6	6	6
Flexure	160x40x40	6	6	6

Table 4.9 Sample nos. and Dimensions for Physical properties tests

Six samples were cast for each mortar formulation, three were immersed in NaOH solution for 28 days at 80^0 C, and the other three were placed in water for 28 days. Then all the samples were put to the test in the UTM, and readings were taken before alkali exposure and after alkali exposure and then, the samples were tested, and results were obtained by averaging the readings for each mix design.

STRENGTH OF OPC MORTAR

There were three mixes for OPC mortars, mainly

- OPCM with natural aggregate
- OPCM with recycled aggregate
- OPCM with glass aggregate

1) COMPRESSIVE STRENGTH

The compressive strengths results were as follows:

Type	**Initial Compressive strength before alkali exposure (MPa)**	**Standard Deviation**	**Compressive strength after alkali exposure (MPa)**	**Standard Deviation**	**Percentage Reduction in Strength (%)**
SO100	35.92	3 .82	29.67	3.07	-17.40
RO100	31.73	2.54	27.35	1.79	-13.80
GO100	10.19	0.68	7.93	1.00	-22.18

Table 4.10 Compressive strength values of OPC Mortar samples with different aggregate types (MPa)

2) FLEXURE STRENGTH

The flexure strength results were as follows

Type	**Initial Flexure strengthbefore alkali exposure (MPa)**	**Standard Deviation**	**Flexure strength after alkali exposure**	**Standard Deviation**	**Percentage Reduction in Strength (%)**
SO100	18.19	2.41	16.58	1.66	-8.85
RO100	21.37	1.84	18.53	1.09	-13.29
GO100	11.87	0.68	11.79	1.13	-0.67

Table 4.11 Flexure strength values of OPC Mortar samples with different aggregate types

STRENGTH OF GPM

There were three mixes for geopolymer concrete cement, mainly

- GPC with Natural Aggregate
- GPC with recycled Aggregate
- GPC with Glass aggregate

COMPRESSIVE STRENGTH

The compressive strengths results were as follows:

Type	**Initial Compressive strengthbefore alkali exposure (MPa)**	**Standard Deviation**	**Compressive strength after alkali exposure (MPa)**	**Standard Deviation**	**Percentage Reduction in Strength (%)**
SF100	12.78	1.98	12.28	1.49	-3.91
SF075	23.77	3.15	22.82	2.52	-4.00
SF050	28.41	1.87	26.75	2.12	-5.84
RF100	18.12	1.55	15.86	1.06	-12.47
RF75	22.56	1.79	20.37	1.16	-9.71
RF050	24.58	2.04	22.64	2.29	-7.89
GF100	3.12	1.14	1.07	0.65	-65.71
GF075	4.20	1.67	3.11	1.04	-25.95
GF050	4.20	0.83	4.05	1.08	-3.57

Table 4.12 Compressive strength values of OPC Mortar samples with different aggregate types (MPa)

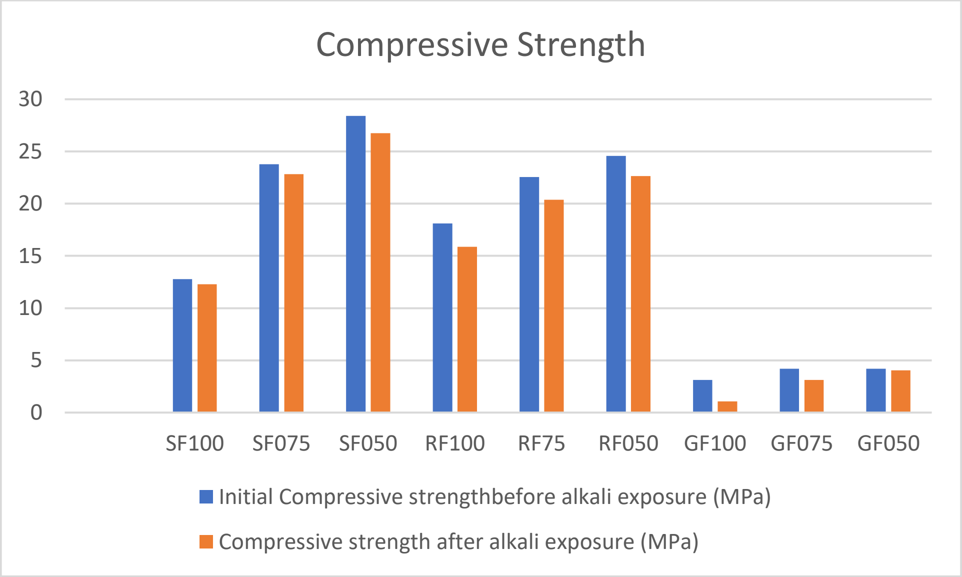
FLEXURE STRENGTH

The flexure strength results were as follows

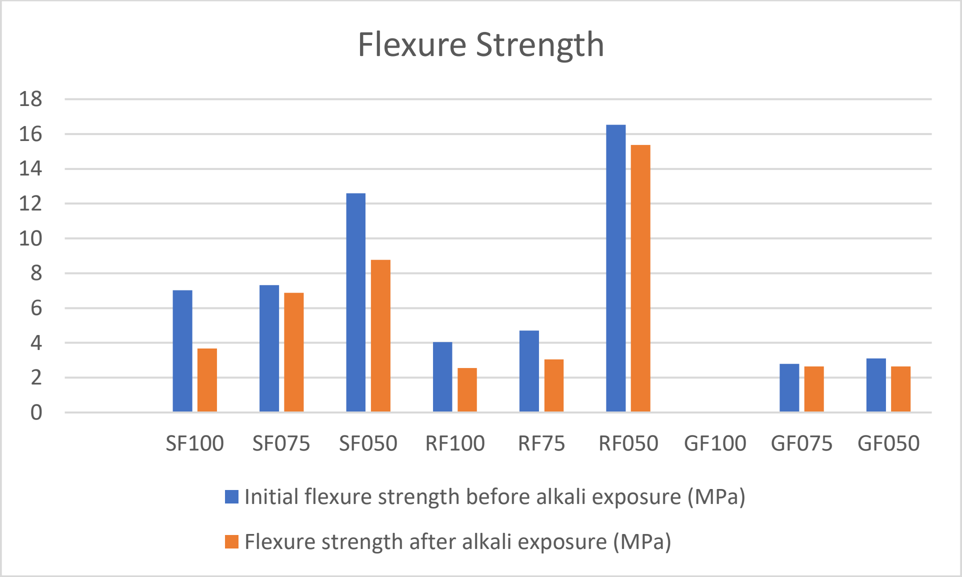
Type	Initial flexure strength before alkali exposure (MPa)	Standard Deviation	Flexure strength after alkali exposure (MPa)	Standard Deviation	Percentage Reduction in Strength (%)
SF100	7.03	1.17	3.67	0.68	-47.80
SF075	7.32	1.89	6.87	1.26	-6.15
SF050	12.59	2.11	8.77	2.36	-30.34
RF100	4.05	1.35	2.56	0.86	-36.79
RF75	4.70	0.78	3.05	0.34	-35.11
RF050	16.53	1.58	15.38	1.83	-6.96
GF100	0.00	0.00	0.00	0.00	0
GF075	2.80	0.41	2.65	0.61	-5.36
GF050	3.10	0.75	2.65	1.00	-14.52

Table 4.13 Flexure strength values of OPC Mortar samples with different aggregate types (MPa)

RESULTS AND DISCUSSION



Graph 4.4 Compressive strength of different mortar bars.



Graph 4.5 Flexure strength of different mortar bars.

Following observations were made.

- In compression strength, the difference is about 7 MPa or 26.4% (SO100—SF050).
- The compressive strength of GPC is almost the same as OPC. But better strength can be achieved by adjusting the mix proportion and slag content. Mix (Sand) with slag content 50% is about twice that of 100% fly ash-based GPM. An increase of 55.01% strength increases by adding 50% slag replacement to fly ash in GPM Mortar.
- The reduction in strength after ASR in OPC is much more than GPC. The amount of strength reduced is around 4-7 MPa in OPC whereas, only 1-2 MPa is reduced in GPC mix. Hence, this proves that the effect of ASR is small in GPC.
- Replacement of natural Aggregate by recycled Aggregate affected the mechanical properties of geopolymer composites. However, geopolymer composites with recycled Aggregate still possess sufficient compressive strength up to 18 MPa, 22 MPa, and 24 MPa with replacement slag ratios of 100%, 75%, and 50%, respectively

CHAPTER 5: Conclusion

OPC has been one of the highest consumable materials in the world. However, the increase in environmental and socioeconomic issues due to high OPC consumption has urged the need for a more sustainable and eco-friendlier alternative. Geopolymer concrete is considered the most reliable substitute for OPC-based concrete. This study assesses one of the grey areas in geopolymer binders, the alkali-silica reaction in geopolymer mortar based on the accelerated mortar bar test results and SEM/EDS analysis results. In addition, recommendations for future works related to this study are briefly discussed at the end of this chapter.

- The results show that the expansion in OPCM is much higher than expansion in GPM. OPCM exhibits higher expansion by a factor of 6 compared to GP-Fly ash samples after 28 days of exposure to NaOH solution at 80 C temperature.
- All Geopolymer mortar samples demonstrated ASR resistance irrespective of the aggregate. Significantly low expansions observed in extremely reactive aggregates such as glass would indicate the low risk of ASR in geopolymer mortar. It should be noted that the severe exposure conditions in AMBT might induce a certain amount of expansion in samples. However, even though the geopolymer mixes have not exceeded the 0.1% expansion limit.
- The effect of reactive aggregate in ASR is more in OPC, but in GP, it is under the limit even after 28 days. The expansion of OPC with glass was 0.37% after 28 days, but in the case of GP, it was between 0.06-0.08, which is under the standard limit of 0.1%. This shows that GPC is better than OPC against ASR.
- All the geopolymer mixes have shown an initial lag in expansion development, which is probably due to the combined effect of high mechanical properties (depicted by high strength gain) and low Ca content in the mix. Thus, the existing short-term expansion tests might not identify the probable ASR in geopolymer mixes.

- The compressive strength of GPC is almost the same as OPC. In the case of compression strength, the difference is about 7 MPa (SO100—SF050). But better stability can be achieved by adjusting the mix proportion and slag content. Mix (sand) with slag content 50% is about twice as 100% fly ash-based GPM.
- The reduction in strength after ASR in OPC is much more than GPC. The amount of strength reduced is around 17-22% in OPC whereas, only 1-2 MPa is diminished in the GPC mix. Hence, this proves that the effect of ASR is small in GPC.
- Replacement of natural aggregate by recycled aggregate affected the mechanical properties of geopolymer composites. However, geopolymer composites with recycled aggregate still possess sufficient compressive strength up to 18 MPa, 22 MPa, and 24 MPa with replacement slag ratios of 100%, 75%, and 50%.
- Adding fly ash and slag can effectively reduce the ASR expansion of high-calcium systems, but this needs to be further verified in CPT or actual structures. ASR in geopolymer mixes increase with the Ca content in the combination. Since GGBFS is the main Ca source in geopolymer, it can be concluded that GGBFS content controls the ASR in geopolymer.

CHAPTER 6: References

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   Jorge de Brito: Universidade Técnica de Lisboa, Instituto Superior Técnico (IST), Lisboa, Portugal
   António Santos SILVA: LABORATÓRIO Nacional de Engenharia Civil (LNEC), Lisboa, Portugal

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   Ian Sims, Alan Poole

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4) **ALKALI SILICA REACTION IN CONCRETE INDUCED BY MORTAR ADHERED TO RECYCLED AGGREGATE**

   M. Etxeberria, E. Vázquez

5) **MITIGATION AND EVALUATION OF ALKALI-SILICA REACTION (ASR) AND FREEZING AND THAWING IN CONCRETE TRANSPORTATION STRUCTURES**

   Richard Albert Deschenes Jr. University of Arkansas, Fayetteville

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6) **EFFECT OF ASR IN GEOPOLYMER CONCRETE**

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7) **SUITABILITY OF HEAT-CURED LOW-CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE FOR PRECAST APPLICATIONS**

   Amin Noushini: UNSW Sydney, Arnaud Castel: University of Technology Sydney and

   Mahdi Babaee: UNSW Sydney

8) **DURABILITY OF GEO-POLYMER MORTAR WITH RESPECT TO ALKALI SILICA REACTION**

   Dinesh Mahanama Habaragamu Arachchige: School of Civil and Environmental

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9) **ALKALI SILICA REACTION (ASR) IN CEMENT FREE ALKALI ACTIVATED SUSTAINABLE CONCRETE**

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10) **INNOVATIVE METHODS TO MITIGATE ALKALI-SILICA REACTION IN CONCRETE MATERIALS CONTAINING RECYCLED GLASS AGGREGATES**

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11) **STANDARD TEST METHOD FOR COMPRESSIVE STRENGTH OF HYDRAULIC CEMENT MORTARS ASTM C109**

12) **STANDARD TEST METHOD FOR POTENTIAL ALKALI REACTIVITY OF AGGREGATES (MORTAR-BAR METHOD) ASTM C 1260**

13) **PHYSICAL-MECHANICAL PROPERTIES OF FLY ASH/GGBFS GEOPOLYMER COMPOSITES WITH RECYCLED AGGREGATES**

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14) **COMPARATIVE STUDY ON MECHANICAL PROPERTIES OF CONVENTIONAL AND GEO-POLYMER CONCRETE WITH RECYCLED COARSE AGGREGATE**

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15) **EFFECTS OF COMBINED USAGE OF GGBS AND FLY ASH ON WORKABILITY AND MECHANICAL PROPERTIES OF ALKALI ACTIVATED GEOPOLYMER CONCRETE WITH RECYCLED AGGREGATE**

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16) **STUDIES ON FLY ASH-BASED GEOPOLYMER CONCRETE**

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17) **STATE-OF-THE-ART REPORT ON ALKALI-AGGREGATE REACTIVITY**

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18) **ALKALI-ACTIVATED BINDERS: A REVIEW**

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19) A REVIEW ON ALKALI-SILICA REACTION EVOLUTION IN RECYCLED AGGREGATE CONCRETE

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20) FRESH AND HARDENED PROPERTIES OF FLY ASH–SLAG BLENDED GEOPOLYMER PASTE AND MORTAR

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21) FHWA USER GUIDELINES FOR WASTE AND BYPRODUCT MATERIALS IN PAVEMENT CONSTRUCTION

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