



Comparative study of Geopolymer and calcium sulfoaluminate as alternatives for Ordinary Portland cement (OPC)

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ABSTRACT

Cement industries are facing two main problems, which are serious issues both for cement researchers and cement manufacturers, like the production of huge amount of greenhouse gases and second is the high cost of the cement, due to the high prices of the fuel consumption in cement plants. The cement producers are therefore under increasing pressure to reduce the use of energy and associated greenhouse gas emission. This paper provides a literature review on two such alternative binders like geopolymer and calcium sulfoaluminate with reference to their history, composition, advantages and disadvantages, hydration and their reaction mechanism.

KEY WORDS: Portland cement, Environment, Production cost, alternative binder.

1. INTRODUCTION

Portland cement is a binder in concrete industry. The two calcium silicate phases like Alite (C_3S) and Belite (C_2S) are indispensable to develop the strength in Portland cement, which form above $800\text{ }^\circ\text{C}$, where alite (C_3S) is preferably synthesized upon increasing the temperature and amount of calcined lime (CaO). Alite gives an early strength development, while belite (C_2S), as longer strength development performance. The annual production of Portland cement is about 3 giga tons on global level [1]. Portland cement concrete has been receiving a great recognition for its versatility, durability, and economic value and relatively low embodied energy compared to other building materials and for its use of local materials, thereby reducing energy and pollution costs associated with material transport. At the same time a number of problems are associated with the production of Portland cement like consumption of huge amount of fuel during clinkerization which is approximately 2-3% of global primary energy. Secondly, approximately one ton of carbon dioxide for every ton of cement is produced both from the calculations of raw material and burning of fuel, which accounts for 5% of man made CO_2 emissions [2]. The cement industry is trying to reduce both energy consumption and greenhouse gas emissions and is actively seeking alternatives to this familiar traditional binding material.

Industrial waste production has become a global issue, which is interestingly recycled in Portland cement and concrete and compensate the two major problems associated with the cement production process. A number of waste materials can be used in Portland cement concrete as supplementary cementing materials, which include fly ash from coal combustion, ground granulated blast furnace slag from iron production, bagasse ash from sugar industries and silica fume from ferrosilicon production. However, these are used to replace only a portion of the cement in concrete, typically in the order of 10-50%. The main interest of cement researchers is to create such binders which utilize mainly the waste produced during different processes.

Additionally the exploration of alternatives to Portland cement can be derived from its shortcomings from certain applications and environmental point of view. For example, rapid repair applications demand a quicker strength gain than the Portland cement concrete can provide. Secondly, environmental conditions with high acidity or high sulfate concentrations can cause substantial degradation of Portland cement concrete. For such conditions, alternatives for Portland cement are demanded meeting the above shortcomings.

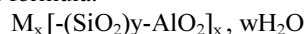
New binders are being developed for concrete that promise to reduce the environmental impact of construction, use a greater proportion of waste materials, and improve concrete performance. These materials represent a substantial departure from the traditional chemistry of Portland cement, and therefore do not benefit directly from the many years of research into its reaction mechanisms, property development and durability. Moreover, new materials have difficulty in finding acceptance in the construction industry, making implementation challenging. In this work some of the alternative binders are discussed which are attracting attention in research and practice, summarizing the present understanding, gaps in knowledge and challenges. Although there are many alternate binders for Portland cement, but in this work only two are addressed like geopolymer cement and calcium sulfoaluminate cement in comparison of Portland cement.

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There are two main factors which are challenges for new concrete. Primarily, fundamental questions with respect to processing, chemical and physical behavior, and performance. Secondly, to establish the standard composition and performance parameters of the materials and to incorporate them into building codes and specifications. These challenges are addressed in this work with respect to two types of new binders.

2. 1. Geopolymer

Geopolymers are becoming more and more popular being a good alternative to Portland cement because of their high strength durability and low environmental impact. General parameters of geopolymers are compared with Portland cement in Table 1, while its advantages and disadvantages are compared in Table 2. Geopolymer was for the first time introduced by Purdon in 1940 [2-3]. Purdon activated blast furnace slags with alkaline solutions and lime, and achieved good compressive strength development. The effect of slag activated with alkali on tensile and flexural strength of cement, solubility of the hardened binder phases, and low heat evolution, was also studied by the same author. Such binding materials are obtained by mixing aluminosilicate with an alkali solution which act as chemical activator. Such binder was named as geopolymers. In 1978, which had an increase in development and the name polysialates was suggested for the chemical designation of the geopolymer. The term Sialate was an abbreviation for aluminosilicate oxide, which is composed of tetrahedral anions $[\text{SiO}_4]^{4-}$ and $[\text{AlO}_4]^{5-}$ sharing oxygen atom. To neutralize the negative charge on the complex of silica and alumina, a positive like (Na^+ , K^+ , Li^+ , Ca^{++} , Ba^{++} , NH_4^+ , H_3O^+) is also present which compensates the electric charge of Al^{3+} in tetrahedral coordination. The Polysialate has the following empirical formula:



Where x is the degree of polymerization, y is 1, 2 or 3, and M is an alkali cation, such as potassium or sodium, generating different types of Poly (sialates) (Figure. 1) like having Si: Al =1, Si:Al =2 and Si:Al =3 known as poly sialate, poly sialate siloxo and poly sialate disiloxo respectively. According to Davidovits 1991, geopolymers are polymers because they transform, polymerize and harden at low temperature and also because they are inorganic, hard and stable at high temperature and nonflammable. During the last decade a number of researchers have reported many aspects related to geopolymers like, the dependence of the nature of raw material for geopolymers. [3], immobilization of toxic metals [4], reaction mechanisms and hydration products [5], the responsibility of calcium metal in geopolymerization [5], the formation of lightweight construction materials [6] and durability issues [7-8].

Aluminosilicate may be of different nature such as fly ash, blast furnace slag, or metakaolin. The reaction product is like a gel, having a network structure similar to organic thermoset polymers, and thus the binders are also called “inorganic polymers” or “Geopolymers”. The solid component of geopolymer unlike Portland cement can be entirely waste-stream materials, particularly fly ash and blast furnace slag, used with very limited further processing. It has been estimated that substituting geopolymer binders for Portland cement in concrete can reduce CO_2 emissions by more than 80% [3]. Recent researches have demonstrated outstanding physical properties of concrete using geopolymer binders, having better properties than those of Portland cement concrete [4,9]. Some authors have demonstrated that geopolymeric matrixes alleviate to a glassy nature, making any surface a graffiti resistant as any organic paint is reluctant to adhere to geopolymer coated surfaces. Moreover geopolymer coated surfaces being permeable to vapor pressure; so unlike to organic coated surfaces do not delaminate from the already existing original surface [10]. Many geopolymer researchers like [11], have demonstrated that coating the concrete with geopolymers for sealing purposes is far effective than any other types of organic polymer coating. However, shrinkage problems associated with, can be solved by appropriate addition of MgO and PP fiber as expansion agent. Some geopolymer researchers [9] investigated that this binder coating is very much durable as compared to other available binding materials, even in the chemically aggressive environment like under saltwater exposure conditions.

However, some problems are also associated with such cement regarding the handling of concentrated caustic solutions. The cost of activators has also been identified as a potential issue, although this is exacerbated by the lack of economies of scale as alkali activation technology is mainly applied in small operations at present.

2.2. Reaction Mechanisms of Geopolymers.

The knowledge of alkali activation depends on two factors i.e. Nature of solid precursor and nature of alkali activator taken [5]. The aluminosilicate systems activated with alkali metal hydroxide, silicate, is hereby discussed. These materials generally form an alkali-containing amorphous gel binder, and follow a conceptually reaction pathway as shown in figure 2. The amount of calcium available for reaction determines the nature of binder gel. There are two types of calcium in the system, the total calcium and calcium, which can actually react; both are actually different from one another [5-6], so the accurate prediction of reactive components is not provided from the superficial mix composition. For instance a high-calcium geopolymer binder generally forms a primary binder phase

of C-(A)-S-H gel which is amorphous to partially crystalline, highly cross-linked, with a moderate degree of Al substitution and a low C/S ratio [7]. On the other hand, lower levels of calcium lead to the presence of “geopolymer”-type gel [7], which is highly cross-linked aluminosilicate gel which bears strong nanostructural resemblance to zeolite frameworks [12-13] but is generally lacking in long-range crystalline order. This gel contains a very low level of chemically bound water, which brings both advantages and disadvantages in performance like thermal resistance is generally excellent, but permeability can tend to be high. This type of gel is increasingly being described in the literature as N-A-S-H gel, but given the low bound water content, it may be more accurately indicated by N-A-S-(H), as in Figure 2. Zeolite crystallization within the binder does tend to take place with high water content, high-temperature curing or extended ageing, and is more prevalent in hydroxide-activated systems [13]. Practical applications of alkali activation technology can also utilize blends of low, high and intermediate calcium precursors such as ASTM Class C fly ash, to achieve a coexisting mixture of the two types of gel, and ideally take advantage of the beneficial properties of each [14]. However, the exact natures of the coexisting gel phases, including the thermodynamic basis of gel coexistence, remain to be determined in detail [15]. When the slag is rich in magnesium, carbonate activators tend towards hydro calcite and hydroxide toward zeolite formation. Silicate-activated binders are quite variable in secondary phase crystallite content and type, depending on the $\text{SiO}_2/\text{Na}_2\text{O}$ ratio of the activation solution and the mineralogical composition of the solid precursor.

2.3. Reaction kinetics of Geopolymers

The development of analytical techniques capable of measuring the rate of gel network. Growth is very important for understanding the reaction kinetics of alkali activation in most cementitious systems. Several approaches have been utilized successfully for the reaction kinetics. The specific case of reaction kinetics in aluminosilicate “geopolymer” systems has been discussed in detail in a recent review of experimental and modeling approaches [11]; the kinetics of hydration of geopolymer slag are more agreeable to analysis by the standard analytical techniques applied to Portland cement [16] due to greater similarities in chemistry and the release of heat compared to low calcium binder systems.

Infrared spectroscopy, conducted both *ex situ* and *in situ*, has provided the detailed information regarding the kinetic and gel-structural effects which take place during alkali activation of low-calcium aluminum silicates [17]. By coupling this technique with other analytical methods, it has been observed, that the initial gel phase formed will differ structurally from the final gel phase observed after extended curing. The presence of heat and moisture will allow the gel to continue rearranging into a more thermodynamically favorable form, increasing in Crosslink density [17], expelling the initially reasonably high levels of bound water [18], and with some form of zeolitic crystallites [19]. These two stages of gel evolution are denoted as “Gel I” and “Gel II”. Unlike the case of Portland cement hydration, where key reacting phases are crystalline and can be tracked using *in situ* diffractometry [20], similar studies of geopolymer binders have only been carried out on very simple model systems. On the other hand, the formation of the “Gel I” phase from a metakaolin precursor has been identified and described using energy-dispersive X-ray diffractometry [21]. Unlike Portland cement, reaction kinetic modeling of the alkali activation reaction processes has not yet been carried out extensively. For low-calcium systems, a detailed reaction kinetic model derived from the basic ideas presented in Figure. 2 has been developed from data obtained by *in situ* energy-dispersive X-ray diffractometry [7] and then successfully applied to data obtained by other *in situ* measurement techniques. Kinetic analysis of closely related systems, like lime-fly ash and fly ash dissolution in alkaline environments designed to simulate cement pore solutions [22], may be able to provide additional information and insight to aid in the further development and validation of reaction models to describe these kinetic pathways, but much remains to be done in this area. In higher calcium geopolymer slag systems, the most detailed models available have been developed from a thermodynamic basis, and then linked to reaction kinetics through parameters describing the extent of reaction and pore solution chemistry [6]. These models utilize techniques which have been utilized very successfully in the analysis of Portland cement-based systems, providing insight into phase evolution as a function of time, but do not incorporate reaction engineering aspects such as rate-controlling processes [3] or other mechanistic details. The availability of detailed thermodynamic data for N-A-S-(H) gels and related phases is currently hindering the application of such modeling approaches in the study of lower-Ca systems.

2.4. Problem associated with geopolymers

Durability is the main unsolved question in the development and application of alkali activation technology. Geopolymer slag systems are capable of showing very good durability [23] but is strongly dependent on the application of sufficient curing systems. Geopolymer binder, formulated correctly, can set and harden at room temperature or even below room temperature. This has been demonstrated on a large scale in Australia by the application of pre-mixed geopolymer concretes in infrastructure mega projects. As there is no reservoir of available

calcium to provide a pH buffer, therefore carbonation may be quite problematic, and so durability, performance is critically dependent on the development of a refined pore structure [21]. Many of the super plasticizing admixtures usually used in Portland cement concretes are not effective in enhancing the flow behavior of geopolymer binders, which are usually degraded by highly alkaline activators [24] which means that the usual water reduction performance expected of these admixtures is not achieved, high-temperature curing or extended ageing, and are more prevalent in hydroxide-activated systems [25]. Practical performance of alkali activation technology also utilizes blends of high, low or an intermediate calcium precursor like ASTM Class C fly ash, to get a coexisting mixture of the two types of gel, and ideally take advantage of the beneficial properties of each [25-26]. However, the exact natures of the coexisting gel phases, its thermodynamics need further detailed study [27]. Crystalline phases, including hydrotalcite phases or zeolites can form as secondary phases, mainly depending on the activator selected. Carbonate activators tend towards hydrotalcite formation, and hydroxide activators can lead to zeolite formation. Silicate activated binders are fairly variable in secondary phase crystallite content and type, which depend on the solid precursor mineralogy and silica to alkali ratio ($\text{SiO}_2/\text{Na}_2\text{O}$).

3.1. Calcium sulfoaluminate cements

This class of cement is represented as CSA, the major constituent of this class of cements is $\text{C}_4\text{A}_3\text{S}$ which constitutes about 30-70% of the total mass. In 1960, $\text{C}_4\text{A}_3\text{S}$ was introduced as a cementitious phase, when Alexander Klein patented it an expansion or shrinkage compensating addition to cementitious binders [28]. Apart from the wide use in Europe and the United States, this class of materials has been produced, used and standardized in China for more than 30 years [28] and are known as the “third cement series.”

Two types of clinkers are known, sulfoaluminate belite clinker which contains mainly $\text{C}_4\text{A}_3\text{S}$ with C_2S and ferrialuminate clinker which contain $\text{C}_4\text{A}_3\text{S}$ with C_4AF and C_2S . The clinkers are interground with different levels of calcium sulfate in order to obtain rapid-hardening, high strength, expansive, or self-stressing cements. Calcium sulfoaluminate cements are being used in China as a binder for many purposes like concrete in bridges, leakage and seepage prevention projects, concrete pipes, beams and columns, pre-stressed concrete, waterproof layers, low temperature construction and [29-30]. Apart from this, due to their low pH and porosity and the ability of ettringite formation to bind heavy metals, blends of calcium sulfoaluminate cements with Portland cement are of interest in the field of hazardous waste absorption [30,6].

Calcium sulfoaluminate cements are becoming more and more attractive due low emission of greenhouse gases as compared to Portland cement [31]. CSA cement releases only 0.216 g CO_2 per gram of cement which is less than half of that produced from Portland cement, 0.578 g CO_2 per g of the cement, when made from limestone, alumina and anhydrite. Similarly the firing temperature used to produce CSA clinker is typically 1250 °C, which is about 200 °C lower than that used for Portland cement clinker which is 1450 °C. Moreover, this type of clinker is easier to grind than Portland cement clinker [32].

3.2. Raw materials and composition

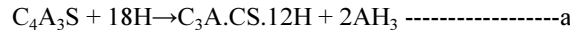
The major raw material for the production of Calcium sulfoaluminate cements are limestone, bauxite and calcium sulfate (gypsum) [33]. The high cost of bauxite causes an economic problem for CSA cements, just as for CAC. To solve this economic problem, researches are being carried out to put into exploring different industrial by-products and wastes like fly ash, blast furnace slag, phosphor gypsum, and scrubber sludge for the manufacture of calcium sulfoaluminate-based clinkers [22]. The clinker production process of the CSA cement is similar to that of Portland cement clinker except the clinkering temperature of 1250-1350°C rather than 1450°C of Portland cement [34].

CSA clinkers contain various other hydraulic phases such as belite, calcium aluminoferrite, free lime, calcium aluminates and gehlenite depending on the composition raw meal [5,9]. To increase the reactivity of the belite phase, which is responsible for late strength development of sulfoaluminate belite cements, minor ingredients can be added to the raw meal [14].

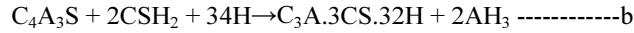
In order to optimize the setting time, strength development and volume stability about 15-25 wt% of gypsum is interground with the clinker. CSA cements with different properties can be obtained, which is depending upon the level of calcium sulfate addition. CSA cements apart from its independent use, can also be used in blends with other cementitious materials like Portland cement, burnt oil shale or limestone [30] to improve their strength development or to formulate rapid setting and hardening binder.

3.3. Hydration of calcium sulfoaluminate cement

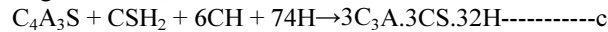
The kinetics of hydration of Calcium sulfoaluminate cement and the development of product are very much influenced by the addition of calcium sulfate or calcium hydroxide [28-29]. When only water is present, $\text{C}_4\text{A}_3\text{S}$ reacts with water according to the following reaction and form monosulfate and aluminum hydroxide,



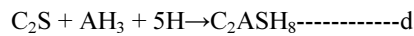
The kinetics of this reaction are very slow, which for several hours remain inactive. When gypsum is added, the hydration kinetics are accelerated to a considerable limit and the formation of ettringite occurs according to the following equation;



When the calcium sulfate is finished before the hydration reaction is completed, again the formation of monosulfate occurs. The ratio of calcium sulfate and C_4A_3S determines the ratio between ettringite and monosulfate in the final hydrated product. When the ratio exceeds the value of 2, only ettringite formation take place, while in lower ratio both ettringite and monosulfate are formed in the final product. With the addition of calcium hydroxide, C_4A_3S reacts very rapidly to form C_4AH_x , while the addition of both calcium hydroxide and calcium sulfate leads to the formation of ettringite according as follows;



C_4A_3S in Calcium sulfoaluminate cements is usually more reactive than the other accessory phases like C_2S , C_4AF and CA [12]. Apart from other hydration products formation of stratlingite (C_2ASH_8) also take place in this class of cement as follows;



The amount of calcium sulfate added and its reactivity control the rate of hydration of calcium sulfoaluminate cements [12-14]. Therefore, the optimum sulfate level for obtaining different types of calcium sulfoaluminate cement is given by the following formula which is based on stoichiometry [30]:

$$\frac{\text{Gypsum}}{\text{Clinker}} = 0.13 \times M \times \frac{A}{S} \text{ -----e}$$

Where

M= molar ratio gypsum/ C_4A_3S

A=% mass of C_4A_3S

S= % mass of SO_3 in Gypsum

0.13= stoichiometric factor

The value of M depends upon the type of CSA cement. When M ranges from 0 to 1.5 with low-calcium sulfate, it yields a rapid hardening or high strength cement [31]. In case when M ranges from 1.5 to 2.5, it gives expensive, while for a value of 2.5 to 6, it give self-stressing cement which generates expansive and compressive stresses in the final, dried mortar or concrete [32]. This causes excessive expansion and crack formation which can be avoided by applying suitable reinforcement techniques.

According to Eq. (e), the properties of the Calcium Sulfoaluminate cements are related to the amount of huge ettringite formation in the hardened system. No sufficient data is available on pore solution chemistry in this system [21,32]. At early age, the liquid phase is dominated by Na, K, Ca, Al and sulfate, till the consumption of added calcium sulfate. During this period the pH value is between 10 and 11. The pH is further increases to about 12.5 when a strong decrease of calcium and sulfate concentrations occurs due to the consumption of gypsum. Silicate concentrations in the pore solutions are lower than for OPC, during the first hours of hydration, while comparable in both systems after several days. Microstructural investigations [33] have shown the presence of ettringite needles, together with monosulfate, aluminum hydroxide, and calcium silicate hydrates, which fill the spaces resulting to a low porosity and very dense microstructure.

3.4. General Properties of Calcium sulfoaluminate cements

General parameters of Calcium sulfoaluminate cements are compared with Portland cement and other alternatives in table 1, while its advantages and disadvantages are compared in table 2. Some of the general properties are explained as follows;

3.4.1 Setting time

The setting times of Calcium sulfoaluminate cements depend on C_4A_3S , the kind and content of minor phases, and the amount and reactivity of the added calcium sulfate. Typical values of initial and final setting times are between 30 min and 4 h [34, 31].

3.2.3.2 Compressive strength.

CSA cements in general reach higher early and late strengths, compared to Portland cement, [34]. CSA cements demonstrate a chemical shrinkage, which is closely related to the density of the water present in the hydrated phases. The ettringite formed, is higher than the density of free water.

Calculations on the basis of thermodynamic modeling have shown that CSA cements have a theoretical chemical shrinkage of about 11 cm³/g cement after 28 days [35], whereas a Portland cement reaches about 4-5 cm³/g. Experimentally the chemical shrinkage of CSA cement was found to be in the same ratio as the predicted theoretically [25]. If ettringite formation occurs in reasonable amounts after setting, expansion may occur, which can be triggered by the amount of added calcium sulfate [23]. The ettringite formation is accelerated by calcium oxide and calcium hydroxide so it's reasonably causes to expansion [36]. Moreover, due to the high water/cement ratio needed for complete hydration, CSA cements tend to undergo self-desiccation, so as a low water-to-cement ratio is used [37]. The durability of building materials made from CSA cements, generally seems to be comparable to material obtained from conventional Portland cement [38].

3.4.2. Acid Resistance

CSA concretes exhibits a high resistance against chemical attack by sulfates, chlorides, magnesium and ammonium salts [39]. This resistance may be attributed to the dense pore structures developed by CSA cements. Porosity measurements have revealed that hydrated CSA cements exhibit mainly pores of a threshold radius below 25 nm [39] and only a minor content of larger pores forming an interconnected pore network [40], leading to high impermeability [41-42].

3.4.3 Carbonation

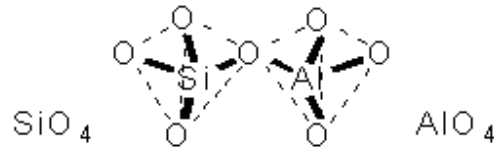
Carbonation depends on the water-to-cement ratio and appears to be more rapid than in Portland cement concretes, leading to the decomposition of ettringite, which may cause a little strength loss [43]. Moreover, the alkalinity of CSA cements is about 1 pH unit lower than for Portland cements, and the steel reinforcement seems to be protected from corrosion [44]. The low alkalinity also seems to be favorable concerning alkali aggregate reactions [45-46].

Table 1. Comparison of different parameters of Alternative Cementitious Material with Portland cement.

Parameters	Geopolymer	Calcium sulfoaluminate Cement	Portland cement
Primary phases/materials	Aluminosilicate, alkali	C ₄ A ₃ S, C ₂ S, CS	C ₃ S
Secondary phases/materials	Aluminosilicate, alkali	C ₄ AF, CA, C ₂ AS	C ₂ S, C ₃ A, C ₄ AF, CSH ₂
Hydrates	Gel (N-A-S-(H) and/or C-(A)-S- H), zeolites, hydrotalcite	AFt, AH ₃ , AFm, C ₂ ASH ₈ C-S-H	C-S-H, CH, Aft AFm
Raw material CO ₂ (g/g) primary phase	Activator NS=0.361	C ₄ A ₃ S=0.216 C ₂ S=0.511	C ₃ S=0.578
Clinkering temperature	Fly ash/slag: N/A Metakaolin:800°C	1250°C	~1450 °C
Grinding energy (kWh/t)	Slag: 50	~20	30

Table 2. Comparison of advantages and disadvantages of Alternative Cementitious Material with Portland cement.

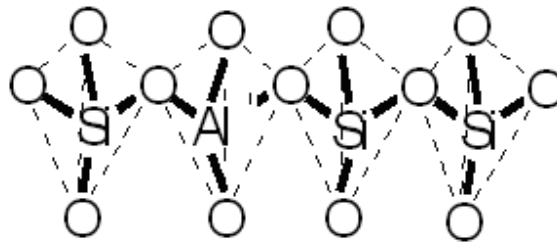
parameters	Geopolymer	Calcium sulfoaluminate Cement	Portland cement
Advantages	<ul style="list-style-type: none"> ➤ Low CO₂ ➤ Low heat of reaction ➤ Heat and acid resistant 	<ul style="list-style-type: none"> ➤ Low CO₂ ➤ Rapid strength ➤ Shrinkage compensating 	<ul style="list-style-type: none"> ➤ Long history ➤ Standard Compositions
Disadvantages	<ul style="list-style-type: none"> ➤ Sometimes slow strength gain ➤ Caustic activating solution ➤ Challenging rheology ➤ Durability unproven 	<ul style="list-style-type: none"> ➤ Durability unproven ➤ Sometimes expansive 	<ul style="list-style-type: none"> ➤ High energy ➤ High CO₂ ➤ Limited early strength ➤ Poor in aggressive environments



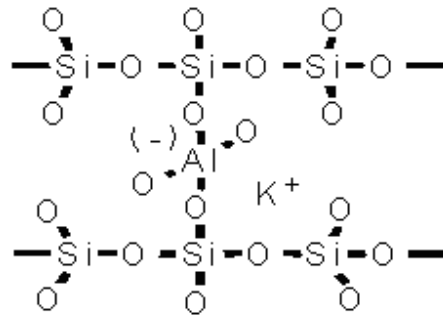
a. Si:Al=1. Poly (Sialate) (-Si-O-Al-O-)



b. Si:Al=2. Poly (Sialate-Siloxo) (-Si-O-Al-O-Si-O-)



c. Si: Al =3. Poly (Sialate-disiloxo) (-Si-O-Al-O-Si-O-Si-O-)



d. Si:Al>3 Sialate link

Figure.1. different polysialates a. Poly Sialate (Si: Al =1), b. Poly Sialate Siloxo (Si:Al =2), c. Poly Sialate Disiloxo (Si:Al =3) and Sialate Link (Si:Al>3)

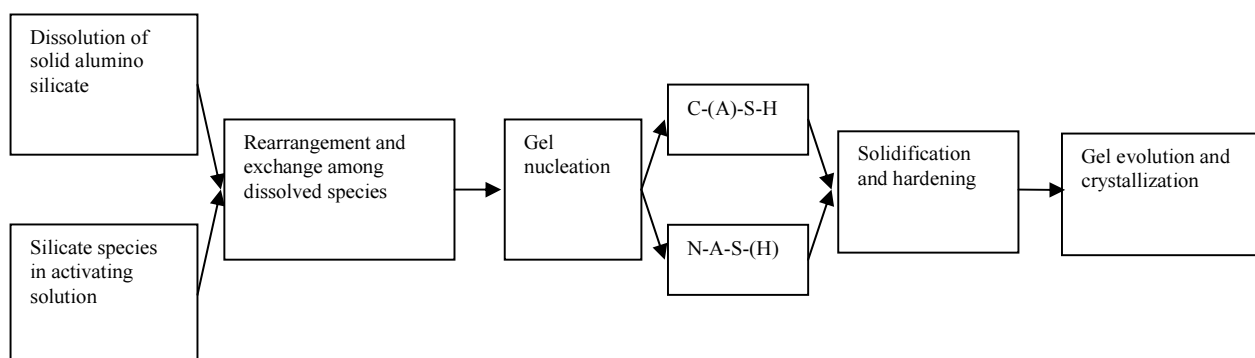


Figure.2. Representation of the alkali activation reaction process.

3.4.4. Conclusion

All alternative binders discussed so far in this study are similar in many respects like composition, energy use, greenhouse gas emission, and performance, at the same time there are also obvious and substantial differences between these materials, remarkably they all have a period of fluidity to enable mixing and substantial strength gains in the absence of applied heat. In the recent years dramatic improvements have been brought in the performance of alternative cementitious binders with respect to reaction mechanisms and property development. The only problem with some of the alternative binders is their higher costs compared to Portland cement and the prescriptive nature of specifications for binders in concrete. It is likely that the use of alternative binders will increase, as the performance-based specifications become more prevalent.

Geopolymer cement offer solution to the cost of raw material as being made from industrial wastes, but the problem associated with it, is the incomplete understanding of the reaction kinetics and products. A number of advances have been made in the development of binder, resulting in the ability to generate good strength development at room temperature and implement the material in large-scale structures.

Calcium sulfoaluminate cements due to their low emissions of greenhouse gases, low energy requirements, rapid strength development in comparison to Portland cement have gained full popularity. The only challenge with this cement is the cost of bauxite, lack of understanding of phase formation and the unknown long-term durability. Cement researchers are advised that the problems associated with the present cement can be removed with such alternatives.

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