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Summarized Concepts in Geo-Polymer Reactions – A Review

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Abstract: Geopolymers are inorganic polymers fabricated as a result of the reaction between aluminosilicate and alkali-activated materials. Various aluminosilicate compounds are used to produce synthetic geopolymers, with the most common sources being metakaolin and industrial by-products (fly ash, mine tailings, red mud, slag, etc.). The starting materials for geopolymers must be rich in alumina (Al_2O_3) and silica (SiO_2). The different geopolymer categories include alkaline cements, mineral polymers, inorganic polymer concretes, hydroceramics, etc., and their applications include thermal-shock refractory, fireproofing, automotive, aircraft interiors, refractory items, decorative stone artifacts, etc. In geopolymer reactions, models are used to explain experimental results by providing additional information, such as the nature of the transition in the intermediate specimen. Knowledge of geopolymer models depends on prior research on aluminosilicates such as sol-gel, zeolites, etc. Decomposition and precipitation reactions bring out the comparison between thermodynamic and kinetic reactions.

1. Introduction

Geopolymers are synthetic inorganic polymers manufactured from the reaction between aluminosilicate materials and alkaline agents, where, after curing, a semi-crystalline amorphous material is generated. The technology of transforming aluminosilicates into advanced inorganic geopolymers exhibits better advantages (chemical resistance, thermal stability, durability, etc) compared to conventional binders or geopolymers (Kamara *et al.*, 2020; Kumar *et al.*, 2025). Much attention is nowadays given to geopolymers due to their ability to reduce carbon dioxide emissions in geopolymer processing and reprocessing of industrial waste planned for disposal in landfills (Kamara *et al.*, 2023). The lattice structure of aluminosilicate geopolymer comprises silica and alumina atoms tetrahedrally arranged with alkali cations balancing the anion on the aluminum (S Kamara, 2025; Wang *et al.*, 2019).

Many people define geopolymers as the alkali activation of aluminosilicates. Geopolymer researchers have still not been able to bring forward a succinct explanation of the term geopolymer and the differences between a geopolymer and a non-geopolymer. Various names have been assigned to different categories of geopolymer materials (Matsimbe *et al.*, 2022), such as alkaline cement, alkali-activated materials, alkali-bonded ceramics, geopolymer types of cement, mineral polymers, inorganic

polymer concretes, hydroceramics, etc (Jwaida *et al*., 2023). Some geoscientists refer to a material as geopolymer when the product of the reaction is amorphous or crystalline zeolite, and get baffled when comparing the reactions of a geopolymer to pozzolanic reactions. Davidovits founded the Geopolymer Institute, centered on geopolymer science, from which his terminology was disseminated. This led to the increased use of the word "geopolymer" in many scientific articles. Geopolymer was asserted as a compound that comprises repeated units derived from the geopolymerization process and not an alkaline-activated aluminosilicate (Luhar & Luhar, 2022). This attracted more interest in geopolymerization reactions and defined the term as the process of combining small molecules, i.e., oligomers, in basic or acidic solutions through covalent bonding.

The compositions of geopolymers and properties like fire resistance, acid resistance, low CO_2 emission, low thermal conductivity, high temperature resistance, low permeability, strong bonding, good durability, excellent chemical corrosion resistance, and environmental friendliness (Kamara *et al*., 2020), etc manifest their various popularly known applications. The principal component that determines the properties of a geopolymer is the ratio of silica to alumina. The silica-alumina ratio is the principal component that determines the properties of geopolymers according to research (Dehghani *et al*., 2021; Živica *et al*., 2015). High-temperature and fire-stability geopolymers, fireproofing, and heat-resistant refractory applications are formed from a higher silicon/alumina ratio (Saidu Kamara, 2025; Kamara *et al*., 2025).

Some applications of geopolymers made from metakaolin, slag, and potassium silicate are thermal shock refractory, automobile, aircraft interior, refractory items, decorative stone artifacts, fire-resistant wood panels, geopolymer cement and concrete, aluminum foundry, sustainable construction material, mine backfilling, porous spheres as novel pH buffers, bricks, porous thermal insulation material, as road material, for immobilization of toxic metals and nuclear waste management, coatings for concrete, as a waterproof surface, etc (Tomar *et al*., 2022). The technology of geopolymer (**Figure 1**) is used to recycle waste materials like red mud and mine tailings generated from mine processing industries (Kamara, 2024; Kamara *et al*., 2025).

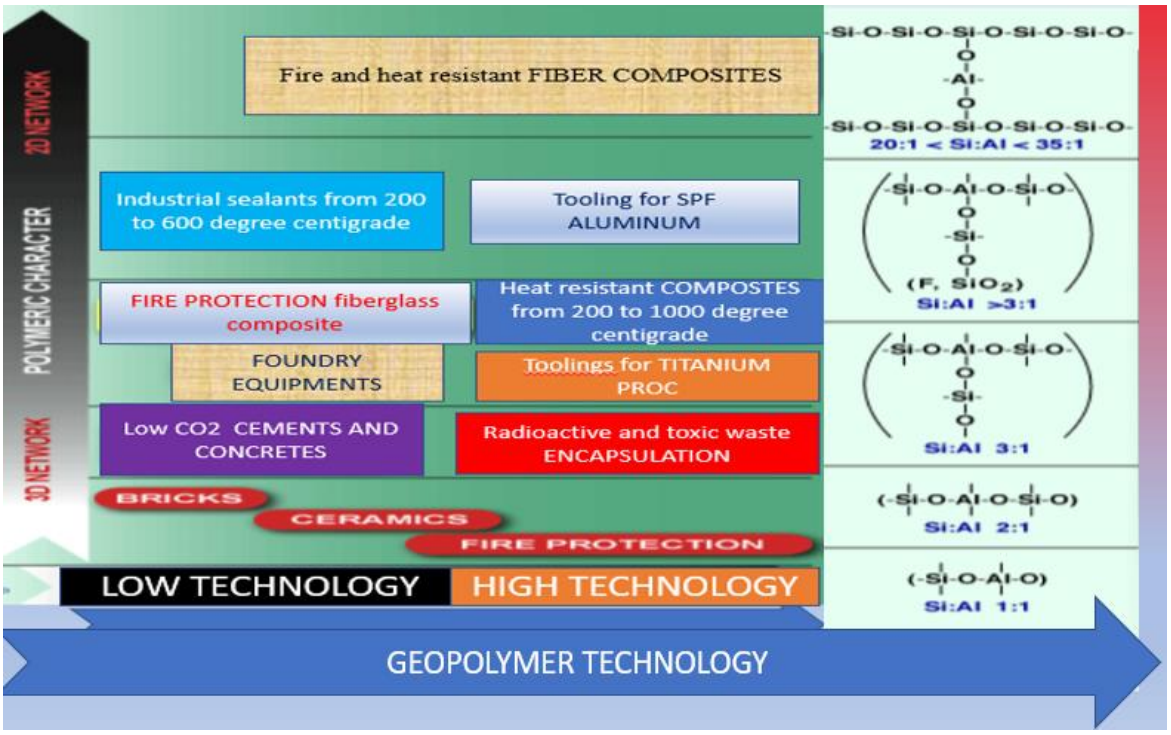

Figure 1. Modified diagram of silica-alumina ratios of geopolymers with names, structures, and applications.

The harmful wastes, composting clay materials, are heated at low temperatures to form precursor materials used for stabilization and as geopolymers for backfilling (Singh & Budarayavalasa, 2021). Geopolymers are used as a replacement for Portland cement in the 3D printing of geopolymer structures and artifacts, and are also used in wastewater treatment for the removal of copper and ammonia impurities (Luhar *et al*., 2021).

2. Reactions of geopolymers

In modeling, it is difficult to form a strong, solid monolith from the primary suspension geopolymeric reactions, but it is, however, a significant characteristic in geopolymeric science and technology. Models are used to explain experimental results with additional information, like the transition nature of the intermediate specimen (Zhang *et al*., 2019). It is important to adequately depict the reactants which are mostly alkali solutions and inorganic precursors. It is challenging to arrive at an adequate model result because atoms in the solvent are well activated.

2.1. Abstract models for geopolymer reactions

Knowledge about geopolymer models mainly depends on previous information and similar research work on aluminosilicate-like sol-gel, zeolite, etc. This has led to the use of polymer models from other fields of research areas with confirmation from experiments to ensure their validity. Researchers have attempted to model alkali activation using destruction, condensation, and crystallization (Feng *et al*., 2024). The "destruction reactions", as defined by the author, show the dissolution of the inorganic precursors. At the molecular level, this consists of the hydrolysis of Si-O-Al and Si-O-Si bonds in the alkaline solutions, which form Si-O-, Si-OH, Al-O-, and Al-OH groups. The inorganic amorphous compound is formed to create new bonds by a condensation reaction in which water is absorbed and regenerated in the initial and final steps. This idea has been added by Provis with more details about other phenomena that occur during geopolymerization, where he combined work on aluminosilicate done by Swaddle (Provis, 2014), together with an equilibrium reaction between the silicate, aluminate, and aluminosilicate atoms and ions generated from a solution of metakaolin.

Condensation and reorganization of the process enhance the strength of the geopolymer after some time. Gel reorganization is termed by some researchers as a rearrangement in the structure of zeolite antecedent crystalline nuclei production (Serrano & van Grieken, 2001). It is also defined as the conversion from an initial Al-rich gel to a Si-rich gel. Geopolymerization is a complicated chain of reactions that it cannot easily be identified and isolated on a step-by-step basis, but we can, however, utilize these conceptualized models to describe and examine the various processes involved in the structural and microstructural formation of geopolymer. The reaction mechanism for metakaolin dissolution was designed by Davidovits using the covalent notion (Davidovits, 2018). He ignored the monomeric concept of $Si(OH)_4$ and $AL(OH)_4$ solutions and proposed the discharge of the orthosilicate molecule $Si(OH)_3OAl(OH)_3$. This assumption or assertion was proven by the presence of this compound in the solution, as shown in the figure below, by suitably dissolving kaolinite in a solution of KOH. The dissolution mechanisms of octahedral Al (kaolin) and tetrahedral Al (metakaolin) are alike without any justification for this controversy.

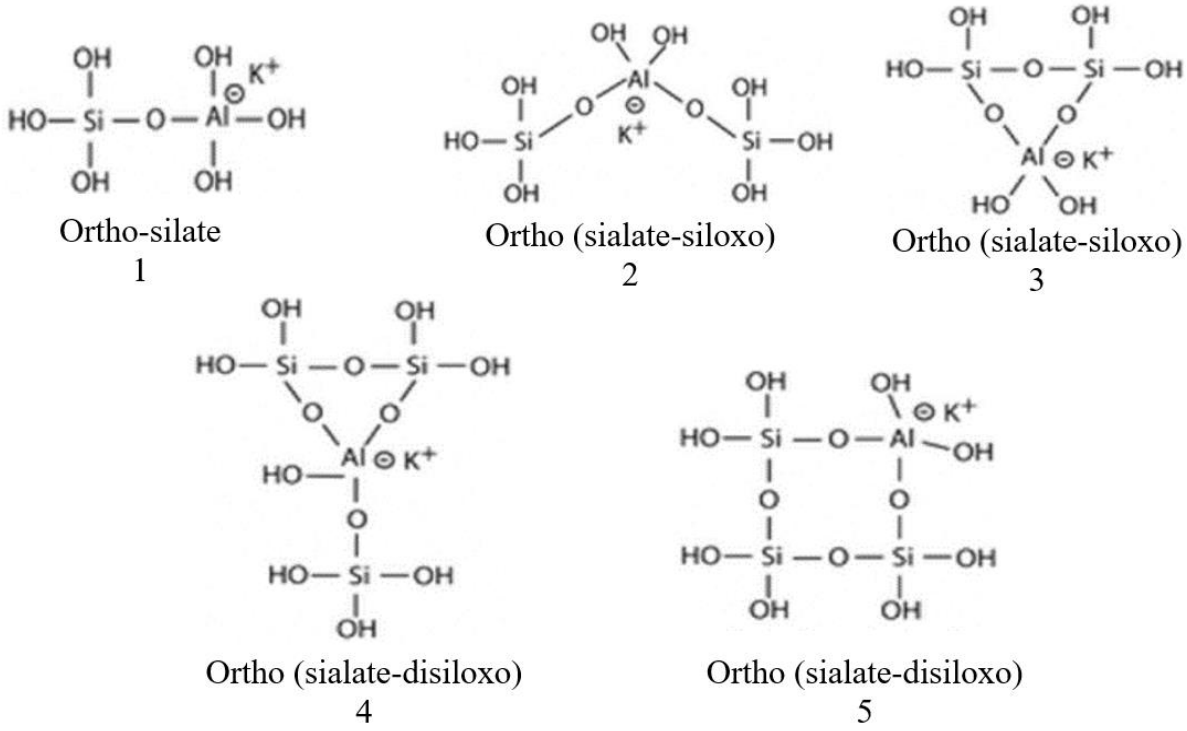

Figure 2. Five ortho-sialate compounds isolated in KOH solution and are precursors of zeolite and geopolymers (Davidovits, 2011).

Soluble ortho-sialate compounds form during the alkaline processing of metakaolin, in which the initial step is the addition of a hydroxyl group to aluminum, thereby rendering it trivalent. The presence of the OH group catalyzes the conversion of silicon into a highly reactive, penta-covalent state, which leads to the breaking of siloxane oxygen bonds and the evolution of a silanol group and a siloxane group, with a balancing alkali metal. The complete cleavage of siloxane oxygen bonds ultimately yields an ortho-sialate compound, as shown in **Figure 2 (1)** above (Zhang et al., 2023). The penta-covalent silicon concept is widely used in sol-gel chemistry to describe the hydrolysis of silicon alkoxides, although it remains to be ascertained in the case of the geopolymers shown in Figure 3:

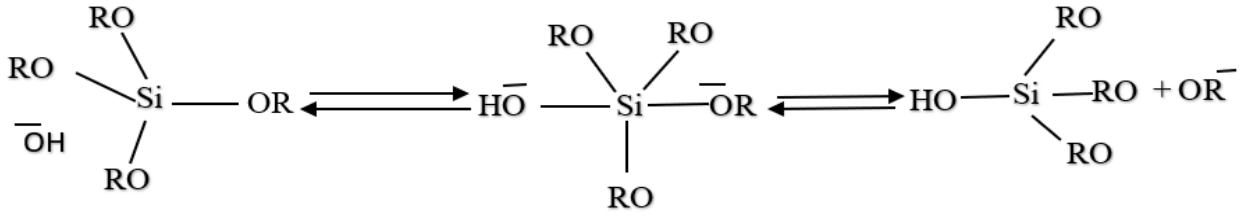

Figure 3 : silicon alkoxide basic hydrolysis.

The addition of soluble silicates to the starting materials determines the sustainable existence of the orthosilicate molecule. The absence of additional soluble silicate results in the formation of tri-cyclo-diasialate, and further polycondensations form a nepheline framework (Pernechele, 2018)**.** The reaction between solutions of ortho-sialate -siloxo and orthosiloxonate produces a linear ortho-sialate-siloxo molecule shown in the 1st structural molecule in Figure 3 above in which a subsequent polycondensation forms the phillipsite framework (Davidovits, 2011). Solutions of ortho-sialate and disiloxonate are reacted together to produce two ortho-sialate-disiloxo cyclic structures shown in the 4th and 5th molecules above in Figure 3 and subsequent polycondensations will result in albite skeleton structure (Davidovits, 2011). The phases show a simple, straightforward conceptual reaction model

among others in geopolymers. Tetravalent aluminum produced from the initial dissolution is a result of the conversion of and $V-A1$ into $IV-A1$ of the excess or the unreacted metakaolin.

2.2. Decomposition and precipitation process of geopolymers and binders

Both geopolymers and inorganic binders involve decomposition and precipitation reaction processes and it is, therefore, conceivable to bring out some thermodynamic and kinetic comparison between them with proven experimental phenomena.

2.2.1. Complex thermodynamic and kinetic reactions

A constant stoichiometric chemical reaction with a volume change can be represented by the equation below

$$6A + 12B + 21C \rightarrow 12Z$$

If Δ $G_{REACTION}$ is negative and the chemical affinity A is positive, then the reaction will be spontaneous, where $\Delta G_{REACTION}$ represents Gib's free energy:

$$\Delta G_{REACTION} = -A = RT\text{In}\left(\frac{Q}{K_{EQUIL}}\right) < 0$$

Chemical affinity A is positive when,$< K_{EQUIL}$, where K_{EQUIL}. is the equilibrium solubility product, and Q is the reaction activity coefficient, which is a function of species activities ai and stoichiometry coefficients ν_i

$$Q = \prod_i^n {a_i}^{vi} = \frac{a_Z^{12}}{a_A^6 a_B^{12} a_C^{21}}$$

It is worth knowing that the reaction rate is determined by the concentrations of the reactants and not by the activities (Brantley, 2008).

$$r = \frac{1}{\nu_i}\frac{d[n_i]}{dt} = -\frac{1}{6}\frac{d[A]}{dt} = -\frac{1}{12}\frac{d[B]}{dt} = -\frac{1}{21}\frac{d[B]}{dt} = \frac{1}{12}\frac{d[Z]}{dt}$$

The rate law, also known as the rate equation, can be determined by the expression below:

$$r = k[A]^{\alpha}[B]^{\beta}[C]^{\gamma}[Z]^{\delta}$$

Where k is the kinetic constant, and α, β, γ, and δ are the partial orders of the reaction. The sum α, β, γ, and δ gives the overall order of reaction, also called molecularity (Brantley, 2008)**.** The partial orders and the stoichiometric coefficients of the reactions are not the same. They are computed by measuring the change in concentration of the reactants. The temperature dependence of the kinetic constant k can be expressed in terms of the Arrhenius equation (Upadhyay, 2006):

$$k = Ae^{(-E_{att}/RT)}$$

Where

A is a pre-exponential factor,
E_{att} is the activation energy of the reaction and
R and T are the gas constant and temperature.

The rate law is a function of concentrations and not of activities because the reaction depends on the molecular collision of reagents. It is complicated to interpret the path of a geopolymer reaction that results in the formation of a very strong geopolymer. The intermediate molecules in this reaction process are produced and consumed during the reaction. The simultaneous reaction may sometimes occur during condensation of depolymerization, in which different products are formed when the same

reactants are reacted together. For instance, a silicate monomer reacts with another silicate monomer or with an aluminate monomer by condensation reaction to form different products. The overall rate for a complex reaction is accounted for by the rate-limiting step controlled by the difference in free energy between the reactants and the transition state complex, which is the highest energy barrier to overcome (Sbirrazzuoli, 2019). The intermediate reactions and the transition state complex are not the same. They are two different processes in which the transition complex state is the only one that is experimentally measured. The activation energy of the process is the energy barrier of the reaction that measures the rate of the reaction at different temperatures. $E_{act} \approx$ 5kcal/mol is applicable in the transfer of diffuse reactions, while $E_{act} \approx$ 20kcal/mol involves a bond-breaking reaction.

For instance, the rate-limiting step is normally interfacial for mineral dissolution at low temperatures, while the change in mechanism and diffusion are the limiting factors at high temperatures. We can determine a complex reaction rate as a function of the initial reaction rate, activity coefficients, and equilibrium constants. The process needs activity correction factors because the rate is a function of concentration, but the equilibrium constants are a function of activity coefficients**.** It is not easy to determine all these parameters even if the mechanism is based on an assumption.

2.2.2. Heterogeneous reactions

Geopolymerization is a heterogeneous reaction of a geopolymer multiphase system. It is pertinent, therefore, to add to the rate law the active surface area of the solid material and any kinetic model to determine their surface area variations due to decomposition or precipitation reactions. Portland cement hydration is also another geopolymeric heterogeneous reaction that has two solid phases and one liquid phase. The two reactions are interfacial, and their rate of reaction can be written as the product of an interfacial reaction rate and the interfacial area S between solid and liquid.

The driving forces ΔG and the interfacial rates vary with time the chemistry of the pore solution varies with time (Liu *et al*., 2024). The rate law for precipitation and decomposition can be written as (Scrivener & Nonat, 2011):

$$R(t) = r_{interface}(\nabla G(t), [ions], \dots) * S(t)$$

$$\Delta G(t) = RT\ln(\beta(t)$$

Where, β (t) = Q (t)/KEQ is the ratio between the activity of the reaction quotient and the solubility of the equilibrium product. If β>1 precipitation occurs, if β<1 decomposition occurs.

There is a connection between decomposition and precipitation reactions in which the dissolution reaction provides the reactants for the precipitation, and the precipitation provides the driving force for the condensation reaction to continue. At the end of the first reaction process in which the hydrates are still not produced, the hydration rate is the same as the decomposition and precipitation reaction $R_{HYDRAT.} = R_{DISSOL.} = R_{PRECIP.}$, thus (Scrivener & Nonat, 2011):

$$r_{precip.} * S(t)_{hydrates} = r_{dissol} * S(t)_{anydr.}$$

At the initial stages of the process, S_{anydr} and r_{precip} are large and the solution is near equilibrium with the anhydrous phases. In the later stages, $S_{hydrates}$ and r_{dissol} become dominant and the solution is nearer to equilibrium with the hydrated molecules. Interpretation of this model with the maximum hydration rate is observed approximately when the surface area of the dissolving and precipitating phases are similar (Scrivener & Nonat, 2011).

The reaction does not hold at the end of the mixing because the surface of the hydrates is

null. The initial decrease in hydration rate is explained in terms of classical nucleation theory which defines the nucleation frequency J ($m^{-3}s^{-1}$) and the induction time for homogeneous nucleation t_{ind} (s) as follows:

$$J = k_0 \exp\left(\frac{f\Omega^2\gamma^3}{(K_BT)^3 In^2\beta}\right)$$

$$In(t)_{ind} = -\frac{f\Omega^2\gamma^3}{(K_BT)^3 In^2\beta}$$

Where

K_0 ($m^{-3}s^{-1}$) is a kinetics constant, f is a form factor,

Ω (m3) is the molecular volume, γ (Jm^{-2}) is crystal-solution interfacial energy,

β is the ratio between the ionic activity product and equilibrium solubility product,

k_B (JK^{-1}) is the Boltzmann constant and

T (K) is temperature.

Before nucleation occurs, the dissolution of anhydrous particles slows down since the solution is almost at equilibrium with the dissolved species ($\beta=Q/K_{EQ}\approx1$) and the driving force $\Delta G_{DISS} \approx 0$. It is worth noting that the reaction decelerates in the final stages of the ordinary Portland cement (OPC) hydration process. Several reacting materials are covered by the products leading to the formation of a shell, and the limiting rate mechanism then diffuses through this shell. A metastable shell is similarly formed on the surface of the reactants to determine the overall process. A decrease in the rate of reaction resulting in a low-solubility coating was also noted as magnesium phosphate ceramic in which boron was added to retard the process (Wu & Chen, 2023). It is also explained that the induction period is when a semipermeable membrane is formed on the surface of the reagents, which will burst later due to the osmotic pressure between the inner and outer solution (Stewart *et al.*, 2018).

2.2.3. Decomposition of metakaolin

Adequate models for condensation reactions, polymerization, and hardening of geopolymer need the species in solution that are generated by metakaolin dissolution over a while.. The dissolution of kaolinite clay in a basic solution is represented by the following reactions (Wang *et al.*, 2016).

$$Al_2Si_2O_5(OH)_4 + 3H_2O + 4MOH \longrightarrow 2Al(0H)_{4^-} + 2Si(OH)_30^- + 4M^+$$

Metakaolin decomposition can also be written as the equation below:

$$Al_2Si_2O_7 + 5H_2O + 4MOH \longrightarrow 2Al(0H)_{4^-} + 2Si(OH)_30^- + 4M^+$$

$$Al_2Si_2O_7 + 3H_2O + 6MOH \longrightarrow 2Al(0H)_{4^-} + 2Si(OH)_2O_2{}^{2-} + 6M^+$$

$$Al_2Si_2O_7 + 7H_2O + 2MOH \longrightarrow 2Al(0H)_{4^-} + 2Si(OH)_4 + 2M^+$$

$$Al_2Si_2O_7 + 5H_2O + 2MOH \longrightarrow 2Al(0H)_3OSi(OH)_{3^-} + 2M^+$$

$$Al_2Si_2O_7 + 3H_2O + 4MOH \longrightarrow 2Al(0H)_3OSi(OH)_2O^{2-} + 4M^+$$

The reactions above present stoichiometric data for possible geopolymerization reactions and illustrate various decomposition mechanisms, depending on pH, deprotonation, and the strength of the detached species or molecule. The final two reaction equations were proposed by Davidovits. Aluminosilicate dissolution is a broad topic. Many factors complicate the determination of the mechanism and rate of metakaolin decomposition. Metakaolin has a complex structure that has only been modeled in recent years, and it is amorphous, making it impossible to account for its

decomposition using quantitative X-ray diffraction (Saidu Kamara, 2025), as in the case of Portland cement and its phases. A key challenge is that dissolved materials precipitate, making it difficult to analyze the species present in the solution and rendering the whole process misleading. The initial exothermic peak cannot be aligned with any hydrolytic process. Aluminosilicate is highly soluble in low-pH acid solutions, which has led many researchers to base their work on the decomposition of aluminosilicate under acidic conditions. This approach is acceptable, depending on the dissolved aluminosilicate and experimental conditions such as temperature, pH, and ions in solution (Skorina & Allanore, 2015).

The decomposition process involves several steps depending on the kinetics rate-limiting step. The steps involved are: 1) diffusion of species to the surface to initiate the decomposition; 2) diffusion of species away from the dissolving surfaces; 3) surface-control formation of an activated complex (or transition state complex); 4) diffusion through a low solubility phase that covers the dissolving phase; and 5) nucleation and growth of a low solubility precipitate that increases the decomposition driving force. The 3rd and 5th mechanisms are the rate-limiting steps for the dissolution of metakaolin, and the 4th mechanism is the possible step for concentrated slurries. It is very bad to extrapolate the kinetic data of metakaolin because different limiting steps render the diluted and concentrated metakaolin different kinetic decomposition. According to the transition state theory and chemical affinity of a material, the rate of dissolution decelerates with the logarithm of time, and it is observed that an increase in the concentration of the dissolved reagent is followed by a decrease in the driving force for the dissolution (Frankel *et al.*, 2018). The equation for the equilibrium between the reagents and the transition state complex is expressed as (Brantley, 2008):

$$r_{net} = -k_{+} \prod {a_j}^{m_j} \left(1 - e^{\left(\frac{n_i \Delta G}{RT}\right)}\right)$$

Where, k_{+} represents the rate of reaction for the dissolution reaction, a_j stands for the activities of the species involved in the formation of the activated complex, m_j and n_i are constants and ΔG can be expressed as in equation 2 above.

The fast decomposition of aluminosilicate at elevated temperatures is interpreted by the transition state theory (Bourcier, 1998). The transition state complex of aluminosilicate salts depends on the aluminum ions in the solution. An increase in the concentration of aluminum will cause a decrease in the rate of the reaction but it remains constant with a variation in silica concentration. The chemical affinity is altered by the presence of aluminum in the solution and also acts as an inhibitor through adsorption on the surface of the aluminosilicate (S Kamara, 2025). The heat of formation of metakaolin, $Si(OH)_4$ and $Al(OH)_4$ accounts that the decomposition of metakaolin is extremely exothermic in an aqueous alkaline solution.

$$Al_2Si_2O_7 + 4H_2O \longrightarrow 2Al(0H)_{4^-} + 2Si(OH)_3 0^- + 4M^+$$

Hydrolyzed metakaolin decomposition processes are endothermic (Catauro *et al.*, 2016), as opined by many researchers, and the dissolution of oxide in an acidic or alkaline medium is well-known to be endothermic (Barry *et al.*, 2019). The first high exothermic and calorimetric peak that first shows is linked with the alkaline dissolution of metakaolin and the deposition of Al^4 on the surface, while an endothermic process is evidenced by the appearance of alumina and silica (Slaný *et al.*, 2023). This concept is evidenced by the tetrahedral arrangement of the aluminum atoms and the excess or unreacted samples in the metakaolin solution. An endothermic decomposition justifies that geopolymerization processes are more favorable at extreme temperatures. Some researchers opined that the presence of Al^4 precipitate or residue, particularly with the presence of silica in the activated solution (Koshy *et al.*,

2015). The SEM images of geopolymer alkaline silicate show excess metakaolin (Steveson & Sagoe-Crentsil, 2005). Estimating excess metakaolin in geopolymerization is complicated because the materials are admixed at a minute scale. Excess metakaolin can be adequately determined using SEM and XRD analysis (Saidu Kamara, 2025). Research has proven that when sodium silicate geopolymer is preserved at 70^0C the excess metakaolin ranges from 25% to 90% depending on the composition of the geopolymer (Hamza *et al*., 2025).

2.2.4. Condensation of aluminosilicate solutions

Silicon does not appear as a cation in aqueous media because it is a metalloid. It exists as oxide and hydroxide in an aqueous solution and can form an oxoanion. It behaves like a weak acid, which increases the polarity of the O-H bond to be easily broken (Petkowski *et al*., 2020):

$$SiO_2 + 2H_2O \rightarrow Si(OH)_4 \rightarrow Si(OH)_4O^- + H^+$$

The hydroxide and oxoanion can form hydroxo-bridges, which may lead to condensation reactions and the formation of oxo-bridges, depending on the conditions of the reaction:

$$2Si(OH)_4 \rightarrow (OH)_3Si - O - Si(OH_3) + H_2O$$

Aluminum oxide is amphoteric and acts as a cation in an acidic solution and as an anion in a basic solution. Aluminum is considered a weak acid as a weak Lewis acid in the synthesis of geopolymer in an alkaline solution (Schubert, 2015).

$$Al_2O_3 + 5H_2O \longrightarrow 2Al(0H)_3 + 2H_2O \longrightarrow 2(Al(OH)_3H_2O) \longrightarrow 2Al(0H)_{4^-} + 2H^+$$

Two different aqueous monomeric species $[AlOn(OH)4\text{-}n]^{(1+n)-}$ and $[SiOn(OH)4\text{-}n]^{n-}$ are produced when Si-OH and Al-OH are deprotonated. Deprotonation of aluminum takes place when the alkaline solution is very high, for instance, when the pH>14. The deprotonated anions form ion pairs with cations, which are contact ion pairs, solvent-shared ion pairs, or solvent-separated ion pairs. The condensation between oxo-anions is restrained by the pairs of ions, which slow down the reaction in geopolymer coagulation. The rate of condensation in sodium geopolymers is faster than in potassium geopolymers because larger ions normally form stronger pairs of ions (Hosan *et al*., 2016). There are, therefore, three states of non-bridging oxygen atoms which are protonated, deprotonated, and ion-paired with a cation. Ion pairs are also formed when silanol and aluminol in aluminosilicate oligomers are deprotonated.

3. The concept of kinetic geopolymerization

Efforts have been made to model the kinetics of the geopolymerization reaction of materials like metakaolin (Siyal *et al*., 2024). The kinetics of the reaction are determined using calorimetry to compute the heat produced divided by the theoretical maximum heat produced. Various writers have measured the heat of reactions from diverse stoichiometric reactions and the heat of formation. The geopolymer gel stoichiometric reaction below was derived to establish the energy of formation of analcime $2NaAlSiO_4{\cdot}H_2O$:

$$Al_2O_3.2SiO_2 + 2OH^- - 2Na^+ + H_2O \rightarrow 2NaAlSiO_4.H_2O$$

The kinetics of various solid reagents with varying Si-Al ratios, particles, etc., were adequately ascertained by using the kinetic model. The experimental results were precisely equalized by employing the kinetic constant. This model did not consider the dissolution and mass mobilization of

solid particles; however, it is an ideal starting point that can be improved by focusing kinetic studies on the rate-limiting steps and rate constants of the different reactions.

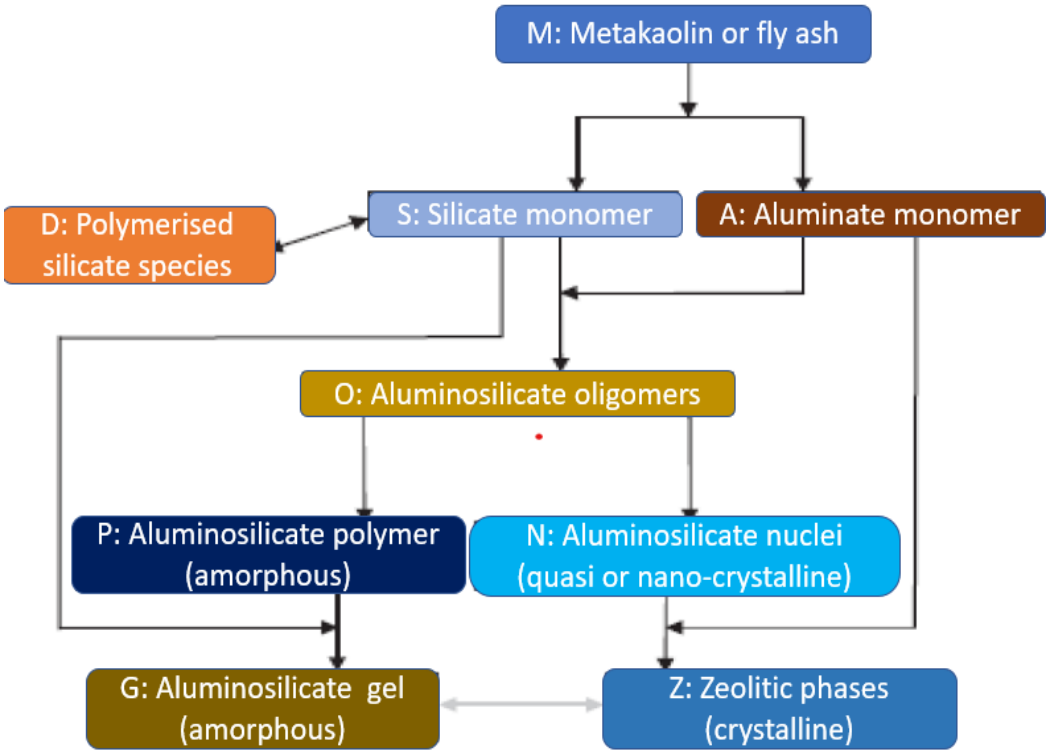

Figure 4 Modified illustration of a kinetic geopolymerization model

4. Conclusion

Aluminosilicate materials are converted into inorganic geopolymers. Geopolymers are alkali-activated aluminosilicate materials. Some geopolymer applications include thermal-shock refractories, automotive, and aircraft interiors. Geopolymer reactions include abstract model geopolymer reactions and decomposition and precipitation processes. The decomposition and precipitation process includes thermodynamic and kinetic reactions, heterogeneous reactions, and the decomposition of metakaolin.

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