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A Comprehensive Review of Geopolymer Materials

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ABSTRACT

Geopolymer (GP) is a novel environmentally friendly cementitious material, and its development has the potential to minimize carbon dioxide emissions generated by the growth of the cement industry. Geopolymer materials have not only outstanding mechanical qualities, but also a number of other good features such as fire resistance and corrosion resistance. Most industrial solid trash and waste incineration bottom ash are built up at will, consuming land resources while also harming the ecosystem. They may be recycled and utilized as raw materials to make Geopolymer. Geopolymer materials can efficiently absorb heavy metals, dyes, and other radioactive contamination, which is extremely useful to the future growth of humanity. However, because of the remarkable qualities of Geopolymer materials, their applicability extends beyond that. The article discussed geopolymerization, raw material sources, activator kinds, and preparation procedures. The parameters that influence the fresh and mechanical characteristics of Geopolymer materials were explored.

Keywords: Geopolymer, Carbon dioxide emissions, Waste Incineration, Activator

1. INTRODUCTION

Geopolymer are inorganic polymer materials that are termed as alkali-activated materials. (AAMs). Natural resources and waste products can be used as the major raw materials in the alkali or acid activation procedure to create Geopolymer. Geopolymer have the advantages of being fire resistant, chemical corrosion resistant, having a high mechanical strength, and being extremely durable [1-6]. Geopolymer materials have been considered alternatives for Ordinary Portland Cement (OPC) since the early 1980s, owing to their low carbon dioxide emissions and performance benefits. Researchers have successfully prepared a Geopolymer coating with exceptional qualities such as high strength, artificial ageing resistance, high-temperature resistance, and superior processing performance that may be utilized as coatings for lightweight polystyrene boards for walls, roofs, and partitions [7]. Geopolymers have been employed in commercial airports and mainline railway sleepers in Australia; geopolymers can also be used to restore deteriorated concrete in military sites [8]. Sustainable development, which demands us to utilize natural resources as little as possible, has recently been recommended all around the world. With the advancement of modernization, the discharge of industrial hazardous solid wastes such as fly ash (FA), slags, and red mud (RM), as well as the contamination of heavy metals, has increased. FA production on a worldwide scale is predicted to be between 71 million and 1 billion tonnes per year. Much FA is disposed of in land fills or ash ponds, and particle entrainment in the air, as well as harmful component seeping into the soil or water, constitutes a severe threat to the environment[9]. The purpose of this work is to cover the synthesis and processing of geopolymer materials, as well as the variables influencing the characteristics of geopolymer materials.

2. GEOPOLYMERIZATION PROCESS

Geopolymers are created by geopolymerizing aluminosilicate materials dissolved in an alkali activator solution at ambient or high temperatures, resulting in an amorphous phase and three-dimensional silico aluminate network structure [10-12]. Although experts have differing views on the reaction mechanism that happens during geopolymerization, the majority believe that the process may be separated into three major phases [13-15].

a. When aluminosilicate materials dissolve in concentrated alkali solution, they create free silica and the alumina tetrahedron unit.
b. The transfer of ingredients, their solidification/gelation, and the condensation reaction of alumina and silica hydroxyl to produce the inorganic geopolymer gel phase ,water is expelled from the structure at this step as a result of the hydrolysis process.
c. The gel phase condenses to produce a three-dimensional network of silico aluminate, which forms a geopolymer when it solidifies

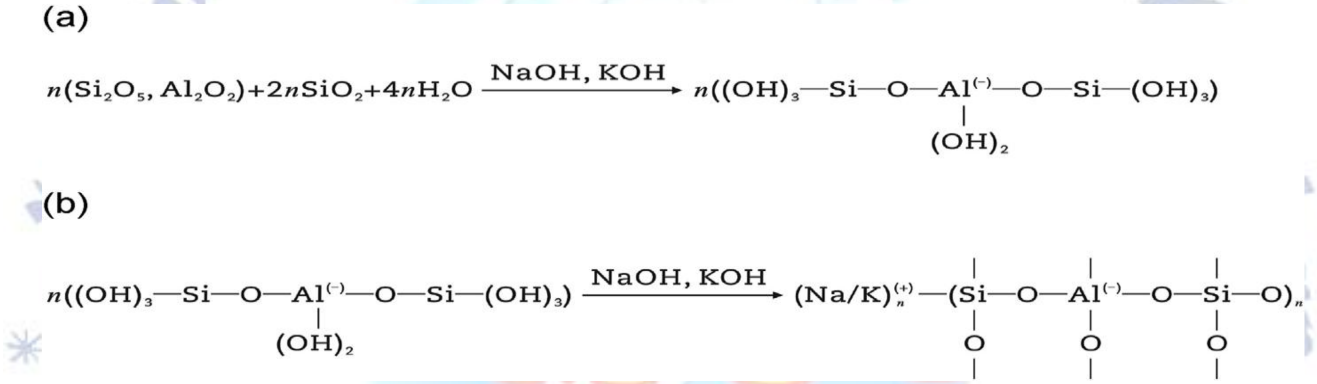

Fig.1 Depiction of schematic representation of Geopolymerization process [16]

In Fig. 1, it can be shown that activators play an important role in geopolymerization. When compared to lower NaOH concentrations, the concentration of 10 M NaOH resulted in the highest rate of dissolution of Si_4 and Al_3 ions in aluminosilicate materials, resulting in a higher degree of geopolymerization[17-18]. The curing temperature is critical to the geopolymerization process. The temperature causes raw material dissolution to speed up, and the faster appearance of an amorphous phase peak in an XRD pattern shows that the greater the temperature, the better for geopolymerization [19-20].

3. SOURCE MATERIALS

3.1 Industrial Waste Exhausts

3.1.1 Fly ash

Fly ash is a byproduct of coal combustion that is classified into two classes: class F and class C. When bituminous coal is burned, a typical form of fly ash with a very low CaO percentage is produced, known as class F fly ash (FFA). The composition of FFA is comparable to that of genuine volcanic ash [21]. Fly ash, an easily accessible by-product with the microscopic form of small spherical particles, is a regularly utilized raw material for the preparation of geopolymers[22]. The high free-CaO level of HCFA limits its use in OPC systems, and its use in creating geopolymer is beyond conception[23-25]. FA has been used since the early twentieth century, and it is typically used as a major component of cement or concrete[26]. It is better for the environment to use FA instead of cement since it minimises greenhouse gas emissions and lowers building expenses. FFA has the benefits of being inexpensive, readily available, having a spherical structure, being rich in high activity aluminate and amorphous silicate, and so on. In an alkali activator solution, high-strength geopolymers may be easily generated[27-28].

3.1.2 Ground Granulated Blast Furnace Slag (GGBS)

Blast furnace slag (BFS) is a byproduct of ironmaking that may be produced at temperatures about 1500 degrees Celsius. Because of its amorphous form, high hardness, and pozzolanic activity, BFS cooled in water, also known as ground granulated blast furnace slag (GGBS), is mostly utilized as a partial alternative for OPC after grinding, depending on the cooling conditions[29-31]. GGBS is extremely reactive in the synthesis of geopolymers, and a satisfactory reaction rate may be obtained at temperatures as low as 0^0 C [32]. When slag is utilised as a cement substitute, less heat is created during hydration, which reduces the danger of cracking[33]. GGBS can be used to increase the porosity, long-term strength, and resistance to sulphate and alkali silicate reactivity of concrete, as well as to lower its water consumption, permeability, and hydration heat [34-35].

In summary, the raw materials might be an Industrial waste exhaust material of the alumino silicate category including silicon, aluminium, oxygen, and other possible components. The appropriate raw materials should have amorphous properties and an exceptional capacity to quickly release aluminium[36].

4. Activator Types

4.1 Alkali Activators

Numerous studies have revealed that alkali activators are commonly used to activate geopolymer materials. Alkaline activators come in both liquid and solid forms. Highly corrosive alkalis, on the other hand, are rarely employed as activators and are rapidly being phased out in favor of various solid activators.

In prior investigations, Na2SiO3 and NaOH were often utilized as activators. As an activator, sodium waterglass was utilized to create MK-based geopolymer with compressive strength of up to 63.8 MPa [37]. The use of $Na_2SiO_3.5H_2O$ solid activator, because part of the water in the mixing phase with the undissolved particles of sodium metasilicate pentahydrate chemical combination reduces the water-binder ratio, the compressive strength of the mortar is substantially better than the regularly used liquid activator[38-39]. The activators Na_2CO_3 and Na_2SiO_3 greatly increased the final setting time of the geopolymers, and compressive strength dropped as Na_2CO_3 concentration rose; and the composite activator activated geopolymer is cleaner than the single Na_2SiO_3 or Na_2CO_3 activated geopolymer. The activators Na_2CO_3 and Na_2SiO_3 greatly increased the final setting time of the geopolymers, and compressive strength dropped as Na_2CO_3 concentration rose; and the composite activator activated geopolymer is cleaner than the single Na_2SiO_3 or Na_2CO_3 activated geopolymer. The most often utilised alkali activators are sodium and potassium-based alkali activators. Previous research has revealed that sodium-based alkali activators have a greater activation efficiency than potassium-based activators for FFA. On the other hand, the usage of potassium compounds in geopolymer systems resulted in greater alkalinity than NaOH. As a solid activator, solid potassium carbonate is effective[43].

5. METHODOLOGY FOR PREPARATION OF GEOPOLYMERS

The majority of geopolymers are classified into two kinds based on their past preparation procedures. One is the preparation of one-part geopolymers due to the status of activators, and the other is the preparation of two-part geopolymers. By eliminating the use of harmful alkali solutions, activators for one-part geopolymers are easier to handle. To begin, all dry materials, including the precursor material and the solid activator, are slowly dried and uniformly combined. The water is then gradually added to the mixture while whisking at a low pace[44-45]. The activator for two-part geopolymers is produced 24 hours before mixing. The created alkali solution is then combined with more water. The liquid components were then added to the dry mixture and stirred until homogeneous [46-49]. Finally, the freshly created mixture is progressively put into the mould by vibration casting, sealed with polyethene film, and then released after 24 hours for curing according to real requirements. However, the use of plastic film is not always essential for producing geopolymers. As a result, while considering whether to incorporate plastic mulch in the treatment process, you should consider the necessity for own study. Fig.2 illustrates the two-part Geopolymer preparation procedure concisely

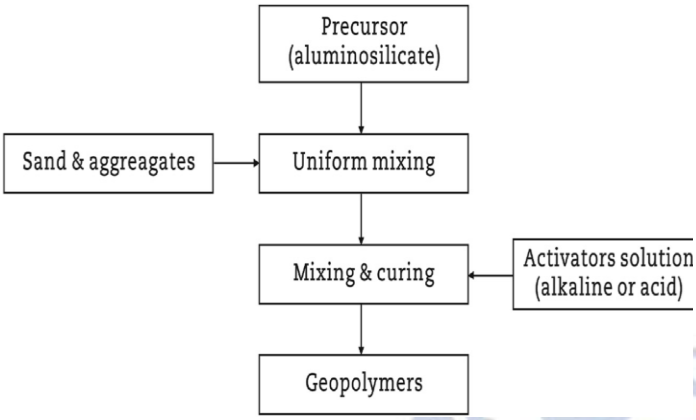

Fig.2 Preparation Process of Geopolymer Concrete

6. GEOPOLYMER MATERIAL PROPERTIES

The cement business pollutes the environment, but geopolymers are preferred by researchers because to their exceptional cleanliness. The application of geopolymer mortar is the most researched. And, when compared to OPC, geopolymer concrete is a novel and sustainable advancement of engineering materials. It is evident that the characteristics of geopolymers are affected by a variety of circumstances. This paper will cover the novel mixing performance, hardening performance, and microstructure analysis of geopolymer mortar and geopolymer concrete. The next section discusses the elements that influence the physical and mechanical characteristics of geopolymers.

6.1 Geopolymer materials performance and affecting elements

6.1.1 Workability

The particle form of raw materials has a significant impact on geopolymer workability. FA particle size reduction enhances FA fineness and the workability of geopolymers[50]. However, slag-based geopolymer materials have poor machinability due to uneven particle form. Furthermore, the reaction products of the FA-based geopolymer are mostly N-C-A-S-H gel. It is rich in aluminium C-S-H gel in FA-slag-based geopolymer. When compared to the FA-based geopolymer, the slag-based geopolymer produces a more compact structure with fewer non-reaction particles, resulting in a reduced workability[51-52].

The workability of GGBS-FA-based geopolymers may also be enhanced by adding a small quantity of superplasticizer; when the concentration of alkali activator is high, there is no discernible influence on the freshness and hardening performance of geopolymer mortar[53]. There have also been several investigations on fibre reinforced geopolymers, with the inclusion of fibre affecting the workability of the geopolymers. The flow value of geopolymer mortar including natural and synthetic fibres was compared to the flow value of control geopolymer mortar, indicating that using all fibres greatly lowers the flowability of the geopolymers[54]. The findings revealed that polyester fibre had a stronger impact on the workability of geopolymers than high strength steel fibre[55].

The type and amount of alkali activators used have a significant impact on the freshness and hardness of geopolymers. Anhydrous sodium metasilicate is a more fluid activator than other activators. The viscosity of geopolymers will be affected by the viscosity of various activators. Furthermore, when the viscosity of the activator solution increases, the workability of mortar is declining in the same way[56]. The geopolymer aggregate has a significant influence on its workability. When researchers employed construction and demolition waste (CDW) instead of natural sand, the fluidity of geopolymer mortar in the fresh condition was low compared to that created with natural sand, which might be attributed to CDW's high water absorption rate, resulting in poor CDW dispersion[57].

6.2 Setting Time

The workability of slag-based geopolymer is poor because to the irregular form of slag particles, and the high slag concentration can accelerate the initial and final setting[58-59]. The addition of GGBS and SF can shorten the setting time of geopolymers, while other materials such as RHA, HCFA, MK, and RM have comparable effects. Different activators produce geopolymers with varying fresh characteristics. Geopolymer concrete activated solely by NaOH without the addition of Na2SiO3 as an alkali activator has a specific impact of postponing setting time[58-59].

6.3 Curing Regime

Geopolymer strength varies with curing condition and age. Geopolymer mortar made with Na2SiO3 and NaOH solution and cured at high temperature has a high compressive strength (56.4 MPa) when compared to ambient curing (42.8 MPa). The cause might be that the higher curing temperature affects C-S-H gel, resulting in a rougher and more porous geopolymer microstructure with many fractures [60].

6.4 Durability Characteristics of Geopolymer Materials

The resistance of geopolymers to severe conditions, such as abrasion performance, porosity, chemical erosion resistance, dry shrinkage, carbonization resistance, and other factors, impacts their durability.Geopolymer concrete has been shown in studies to be more durable than OPC concrete in the majority of circumstances [61]. Furthermore, reducing drying shrinkage helps to increase the durability of geopolymers.The Ca/Si molar ratio has the biggest effect on the drying shrinkage rate of AAMs. When compared to selfcompactness mortar, the addition of recycled glass fibre can reduce the drying shrinkage rate of FA-slag based geopolymer mortar. The results suggest that replacing FA with basalt fibre may minimize the dry shrinkage of the geopolymer paste and make it more homogeneous and compact as the replacement rate increases[62].

7. CONCLUSIONS

The conclusions are as follows:

1. The geopolymerization process is divided into three steps: the dissolving of the precursor, the production of the first gel, and the development of the silicate network structure.
2. Geopolymer materials are abundant in active si licon and aluminium. MK, FA, BFS, RM, bioma ss ash, and other regularly used geopolymer ra w materials include steel slag, SF, volcanic ash, waste glass, coal gangue, diatomite, bauxite, hi ghmagnesium nickel slag, and others.
3. Sodium hydroxide, sodium silicate, sodium carbonate, sodium sulphate, and calcium carbonate are typical geopolymer activators.Mostly Sodium based alkaline activators are utilized as they were less cost.
4. Geopolymers can be prepared in a variety of w ays.It is important to note that the great majorit y of geopolymer materials are now the solid ing redient to mix, and then fully combined with th e liquid mix.
5. Geopolymers, which have outstanding mechani cal qualities, have been employed in cementitio us materials. The kind, particle size, and chemic al makeup of raw materials are all important co nsiderations. The strength of the geopolymers i s affected by their solid and liquid states, as wel l as the kind and concentration of the activator When the curing temperature is between 60 an d 100 degrees Celsius, the strength of the manufactured geopolymer increases. Geop olymers are also influenced by aggregate partic le form and chemistry.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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