Review Article

Friendly Environmental Geopolymers and Its Application: A Short Review

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Abstract

One of the concerns of today's industrial societies is to achieve sustainable development through the reduction of waste materials or the decrease in the emission of greenhouse gases such as CO_2 which today is stated in many international agreements and requirements for it has been concluded by the agreements between the countries of the world, and due to the increasing trend of global warming it is possible to create more encouraging or binding agreements, therefore many researchers are trying to achieve these goals. There are various ways to reduce the production of greenhouse gases during the construction of parts and building materials, and a significant part of them have been directed towards the production of a new type of environmentally friendly material called geopolymers. This category of materials, which have the ability to use waste materials as raw materials for their construction due to their very good mechanical and chemical properties, has been able to find various applications that, due to their similarity to concrete structures, are suitable alternatives for them as structures and building materials. In the following research, an attempt has been made to study geopolymers from the point of view of their formation, applications and properties.

Keywords: Geopolymer, Waste Material, Alumina-Silicate, Cement, Concrete.

1. Introduction

Geopolymers are inorganic materials that have an amorphous structure and their structural bonds are covalent. For this reason, geopolymers are very similar to ceramics, and some researchers consider them to be among the ceramic materials. The way it is formed is a chemical reaction between raw materials with a high percentage of alumina silicate with an alkaline or acidic solution as the activator [1]. In order to study the 3D network structure formed by geopolymers, many models have been proposed and studied by researchers. One of these models has been studied in Fig. 1. In this research, the Si-Al ratio is important and has been taken to be 2.81, which is a large atomic cluster, indicating a disordered, porous but compact structure [2].

Therefore, a wide range of mineral, natural or synthetic materials can be used, provided they contain compounds rich in aluminum oxide, silicon oxide and limited amounts of iron oxide, calcium oxide or magnesium oxide [1]. The first studies on geopolymers began around the 1930s, based on research into the manufacture of products based on aluminosilicate minerals. More specifically, geopolymers were first invented by Davidovits around 1978-1979, Davidovits' attempt to use these materials as a reliable alternative to Portland cements, the purpose of this study is to have environmental benefits and suitable mechanicalproperties of this class of materials [3].

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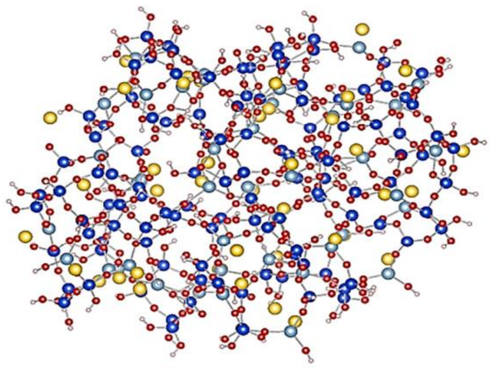

Fig. 1. Schematic of a structural model of a geopolymer with a Si-Al ratio of 2.81 and 800 atoms [2].

New materials were used in construction materials ahead of other traditional competitors [3].After a large number of scientists and researchers had turned their attention to geopolymers, the development of their applications increased rapidly at the end of the 20th century, and in the meantime Davidovits' efforts to formulate and diversify their various production methods were significant. In general, geopolymers are considered synonymous with cement and concrete, but in reality, this category of materials has fundamental differences with cement and concrete, among which it can be pointed out that geopolymers are basically mineral materials. They are made from aluminosilicates that are activated by alkaline or acid solutions. On the other hand, Portland cement is made by heating limestone and clay at high temperatures and turning them into clinker, which is then ground. The primary binding factor in Portland cement is hydration, so where water reacts with calcium silicates it leads to the formation of calcium hydrates and this is the main factor that creates strength [4].

2. Nature of Geopolymers

2.1. Raw Materials

Geopolymers can often be classified in two ways, the first classification is based on the raw materials required for geopolymers and the second classification is based on their manufacturing methods [5], as shown in Fig. 2.
According to the classification of geopolymers based on raw materials, it is possible to mention geopolymers based on metakaolin, which is calcinated clay metakaolin and is considered one of the minerals rich in silica and alumina. On the other hand, if the mineral kaolin, a type of natural clay, is used, kaolin geopolymers are formed. It is even possible to use volcanic rock powder, a silica-rich rock, to make geopolymers. However, there is another category of geopolymers that are formed from industrial wastes generated by various industrial processing methods; some of these materials are not only considered useless wastes, but are also highly toxic and harmful to the environment and to the health of living organisms. For example, fly ash (FA) based geopolymers use fly ash as a raw material rich in silica and alumina [6]. This material is often the result of coal combustion. On the other hand, ground granulated blast furnace slag (GGBFS) can be used as a waste by-product of the steel production process [6]. The ground granulated blast furnace slag geopolymer also contains significant amounts of aluminum oxide and silica. In recent years, the problem of recycling and use of plant and agricultural waste materials has also been raised as a challenge; Most of the waste materials produced in a mechanized way and in large volumes can be used in building materials and often, after collection and incineration, turn into ashes rich in minerals such as silica and alumina, among which we can mention the construction of geopolymer from Rice husk ash (RHA) [7]. The constituents of fly ash, ground granulated blast furnace slag and rice husk ash are given below and in Table. 1.

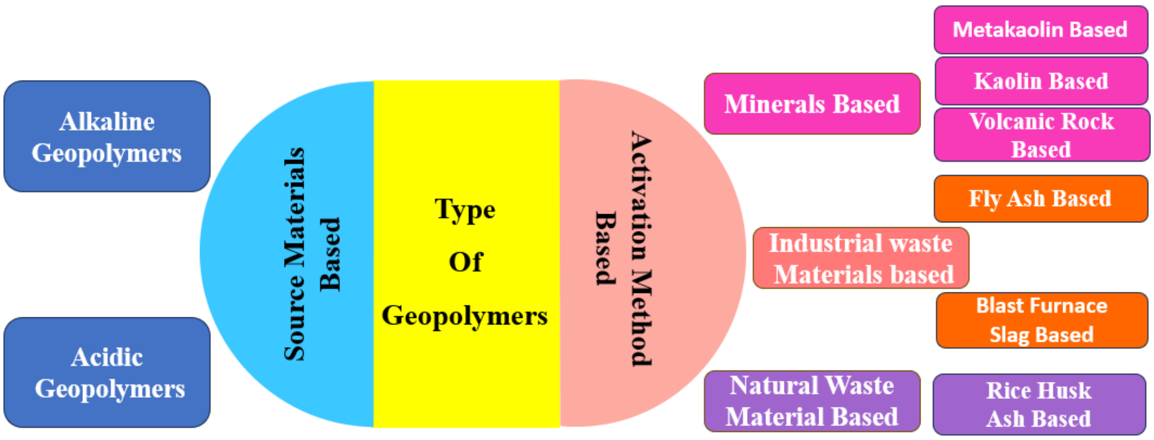

Fig. 2. Classification of geopolymers based on raw materials and production methods[5].

Table. 1. Fly ash, ground granulated blast furnace slag and Rice husk ash chemical composition.

Alumina Silica powder	Oxide compounds (wt.%)							Ref.
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	MgO	
Fly ash	66.56	22.47	3.54	1.64	1.75	0.58	0.65	[8]
	63.13	24.88	3.07	2.58	2.01	0.71	0.6	[9]
ground granulated blast furnace slag	32.52	13.7	0.76	45.83	0.48	0.25	3.27	[10]
	34.11	15.36	0.83	35.99	0.62	0.4	6.58	[11]
Rice husk ash	89.47	0.83	0.53	0.68	0.17	0.22	0.37	[12]
	93.46	0.58	0.52	1.03	1.82	0.08	0.5	[13]

In terms of production and activation methods, we can talk about acidic geopolymers, which are activated by acidic solutions such as phosphoric acid, and of course they are not the most common method, and alkaline geopolymers, which are more common than acidic methods. And alkaline solutions such as sodium or potassium silicates are used.

3. Characteristics of Geopolymers

Geopolymers have very desirable and diverse properties, which are discussed in Fig. 3. As they are often proposed as substitutes and competitors for construction products, more attention has been paid to the required properties of construction materials in the study and comparison of properties [14].
Among the various properties of geopolymers, thermal properties are important; the resistance of geopolymers to high temperatures means that these materials do not collapse and are not destroyed at high temperatures, so they can be used to make products used in high temperature environments. Used as coatings or materials directly exposed to fire [6].

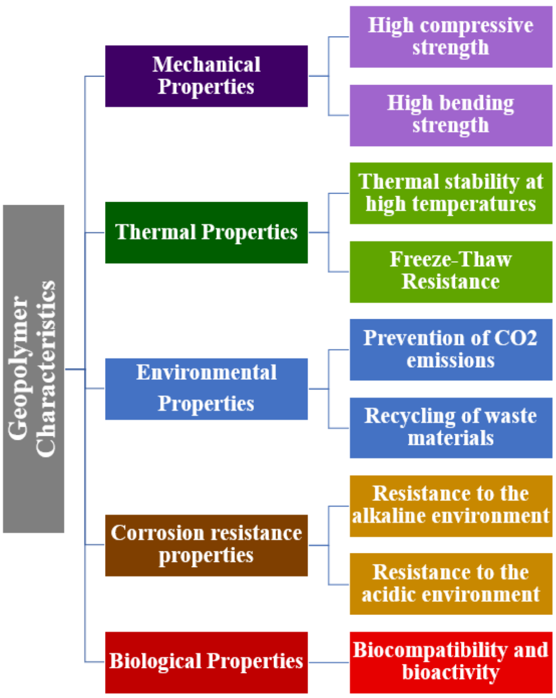

Fig. 3. Classification of geopolymers on the basis of their properties[14].

On the other hand, these materials also have various environmental benefits: for example, by using waste materials and industrial waste in the production of geopolymers, not only has waste been reused, but by reducing the production chain of some products based on the use of fossil fuels, the production of carbon and the resulting greenhouse gases has also been limited [15].
This is an important issue in achieving sustainable development in industry, particularly in the construction industry. For example, compared to Portland cement, the production process of geopolymers results in a 5-7% reduction in CO_2, often due to the absence of heating and processing of limestone in the production of geopolymers [16,17]. The strength and durability of geopolymers is also higher compared to Portland cement products, due to the formation of strong bonds with aggregates, and they can be replaced with concrete products, for example, their compressive strength is higher and their microstructure geopolymers have less porosity, which also effectively increases the final strength of the piece. In general, geopolymers have a high compressive strength of around 100 MPa [15,18]. In addition, the speed of reaction and curing of geopolymers is also a major advantage. Another important issue that can be investigated in the manufacture of geopolymers is the effect of the type and form of additives on the strength of the manufactured parts. Table. 2. shows the compressive strength of geopolymers made from different raw materials and under different curing conditions.

Table. 2. Investigation of the compressive strength of a variety of geopolymers.

Alumina Silicate Powder	Curing Condition	Compressive Strength (MPa)	Ref.
Low calcium Fly ash	80°C for 24hr	60.6	[19]
High calcium Fly ash	60°C for 24hr	48.2	[20]
Blast furnace slag	80°C for 120hr	72	[21]
Kaolin	100°C for 24hr	27	[22]
Metakaolin	70°C for 24hr	34.81	[23]
Volcanic mud	60°C for 72hr	44.8	[24]

For example, in the study by Korhonen et al [15], which investigated the effect of various additives on the porosity, shrinkage and strength of finished geopolymer parts, it was found that the addition of ground granulated blast-furnace slag and gypsum resulted in the formation of a needle-like structure, However, the addition of fly ash with spherical morphology and gypsum creates a porous structure without the formation of needle structures, which leads to a decrease in strength and an increase in the final shrinkage of the part. Fig. 4. shows scanning electron microscope images of geopolymer samples containing fly ash and ground granulated blast furnace slag.

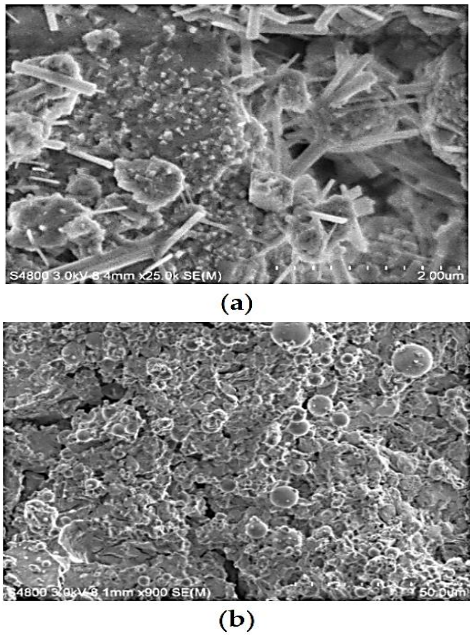

Fig. 4. Scanning electron microscope images of geopolymer samples containing a) ground granulated blast furnace slag with gypsum and b) fly ash with gypsum [15].

The resistance of geopolymers to environmental influences and reaction with corrosive environments is also significant, whereas Portland cement is more sensitive than geopolymers to environmental factors such as sulphates and chlorides and is subject to corrosion and degradation [4,16]. But resistance to environmental factors such as sulphates and acids is one of the other desirable properties of geopolymers. They are also resistant to freezing and have low shrinkage during construction. Cracking during curing is very low in geopolymer products, which greatly enhances their corrosion resistance. Cracking due to curing is very low, which is one of the other characteristics of corrosion resistance of polymers is considered [15,8]. In time, geopolymers have been able to find different applications, which have been discussed in two areas: as building materials needed by the construction industry, or as high-temperature ceramics. used as scaffolds in tissue engineering [25]. Most importantly, the success of geopolymers, environmental challenges and the ability of these materials to reuse industrial waste or reduce CO_2 production [3,6].

4. Applications of Geopolymers

Initially, geopolymers were intended to be used as a substitute for cement, but over time, as research developed, they were used first in the construction of various building materials and then in various other fields. Some of the applications of geopolymers are shown in Fig. 5., and the products made on the basis of different applications are examined below.

4.1. Geopolymer Concrete (GPC)

Geopolymeric concretes are a new category of concretes that have attracted attention because of the high resistance of these materials to chloride corrosion, because of the possibility of using them in environments with harsh weather conditions or with a high degree of corrosion, such as coastal areas exposed to high humidity, which can be mentioned for the construction of structures such as bridges, concrete products for the construction of pavements, retaining walls, water tanks, prefabricated concrete products for bridge decks and railway crossings [7,14,26]. A schematic of the formation of geopolymer concrete is shown in Fig. 6.

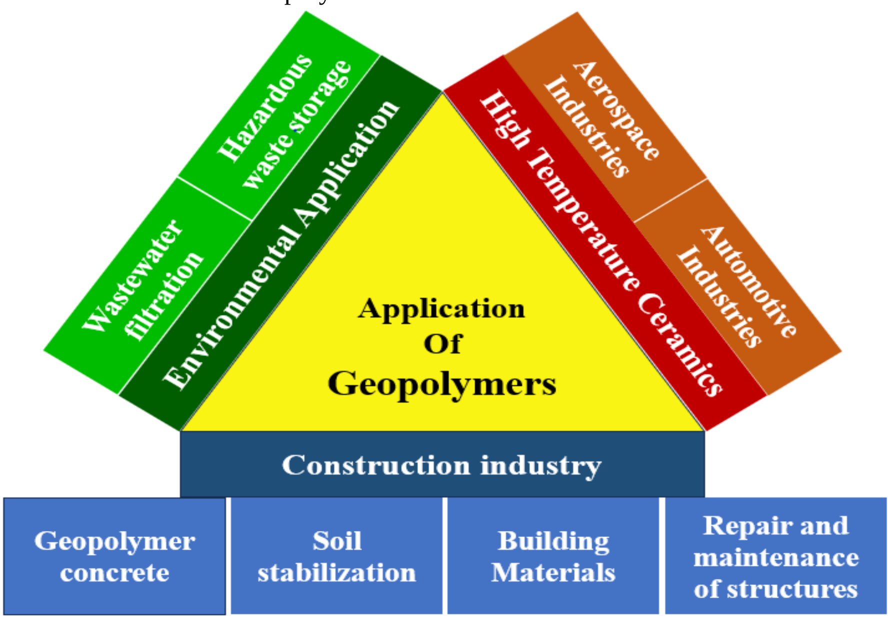

Fig. 5. The applications of geopolymers.

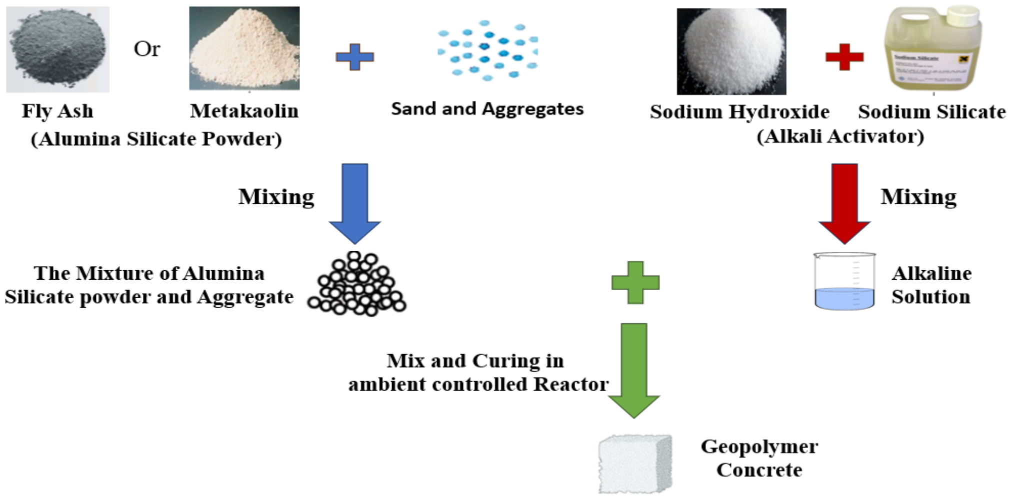

Fig. 6. Schematic of the production steps of geopolymer concrete with alkaline activator[14].

Table. 3. Investigation of production conditions of geopolymeric concretes.

Type of Alumina Silicate Powder	Activator	Aggregate Type	Curing conditions	Ref.
Fly Ash and Metakaolin	$NaOH+Na_2SiO_3$	Silica sand	80°C (2hr) + 20°C and 70%RH (2,6,27days)	[27]
Fly Ash and Ground Granulated Blast Furnace Slag	Na_2SiO_3	Silica sand	90°C(3days) + Curing at 23°C (1day)	[28]
Fly Ash	$NaOH+Na_2SiO_3$	Sand coarse aggregate	Ambient temperature For 7 and 28 days	[29]
Ground Granulated Blast Furnace Slag and Corncob Ash	$NaOH+Na_2SiO_3$	Fine coarse aggregate	Immersed in water in 28 days	[30]
Ground Granulated Blast Furnace Slag and Cow bone Ash	$NaOH+Na_2SiO_3$	River sand and granite	Ambient curing for 7,14,28 and 90 days	[31]

The conditions for the production of geopolymeric concretes depend on factors such as the type of aluminosilicate powder used, the activator, the type of aggregate used and the curing conditions. For this reason, Table. 3. shows some of the research carried out in this area.

4.2. Soil Stabilizer

Another geopolymer product developed for the construction industry is geopolymer soil stabilizers, where geopolymers can be used to increase the mechanical properties and loading capacity of the soil bed, which is highly desirable for the foundation of structures [26].

4.3. Building Materials

Geopolymers are also used to produce low carbon building materials such as panels or prefabricated structures used in building construction, and are a suitable alternative to some traditional materials such as clay bricks. Their ability to use industrial waste materials such as fly ash, blast furnace ash, leads to their acceptance to reduce environmental impact [21].

4.4. Hazardous Waste Storage Products and Filtration Waste Water

Among the other environmental applications of geopolymers, we can mention the storage of hazardous and toxic wastes, which is an important step in creating sustainable development in waste management by storing and enclosing wastes with these materials [32]. It is also possible to use geopolymer materials in the production of foams, as these materials have shown a favorable ability in the process of water purification and absorption of heavy metals [33].

4.5. High Temperature Structures

Due to the low shrinkage of geopolymer parts during construction and, of course, the reduced cracking that occurs in the parts, as well as the stability and high thermal resistance of geopolymers, which are mostly composed of alumina and silica, they can be used to make ceramic parts. The highest temperature at which these parts operate means that they are used in many different sectors, such as aerospace and automotive

[34]. Geopolymers can also be mentioned as inorganic binders used at high temperatures to the extent that they can be used as a composite matrix in the manufacture of ceramic composites [35].

4.6. Repairing Stone and Concrete Structures

Geopolymers can be used as mortars for the restoration of structures and even ancient buildings due to their versatile structure and their correct and fast setting [5].

4.7. Emerging Applications

In recent years, of course, geopolymers have been used in modern and advanced scientific fields such as medical technology, where they are used to make porous scaffolds for tissue engineering and cell growth [25].

5. Conclusion

Geopolymers have been able to attract the attention of researchers and manufacturers due to their favorable properties in terms of mechanical, thermal and corrosion resistance compared to traditional building materials such as cement-based products. It used industrial or natural waste materials and, in addition to the recycling of this category of materials, it reduced the emission of greenhouse gases caused by the methods of production, processing and cooking of raw materials used in traditional competing products, which he considered today as the strength of geopolymers is discussed. The development of the raw materials used in geopolymers, which contain a wide range of metal oxides with a higher percentage of aluminum oxide and silicon oxide, is important, as is the importance of providing the raw materials used in the manufacture of this category of materials from waste materials. It is welcomed by researchers, also considering the appropriate properties that this class of materials has shown, finding and developing their applications in different fields can help the increasing progress of geopolymers.

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