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# A Review of Properties of Geopolymer Concrete

Vivek Mehrotra*

**_Abstract_**

*The growing need for concrete around the world has led to both more concrete being made and more of it being used. Carbon dioxide is released into the atmosphere when regular Portland cement is made, which contributes to global warming (OPC). because concrete that is good for the environment needs new kinds of binders. Using different binders could cut down on the energy needed to make traditional concrete and the amount of greenhouse gases it gives off. Portland cement puts out more carbon dioxide into the air than geopolymer. Geopolymer is an inorganic alumino-silicate polymer that is made without cement or water. Geopolymers are glues made from solid alumino-silicate and an extremely alkaline activating solution. Geopolymers can be made from things like fly ash and clay, which both have alumina and silica in them. In the last few decades, geopolymers have become a more popular alternative to Portland cement because they are more sustainable, durable, and long-lasting than Portland cement. Geopolymer concrete looks nice and lasts a long time. The building gets stronger, which makes the number of cracks and breaks go down. This paper makes geopolymer mortar and concrete last longer, be easier to use, and be used in more places. Workability and strength are both affected by the way and temperature of curing, as well as by the shape of the aggregate, its strengths, its moisture content, how it is prepared, and how it is graded. Other things that can make a difference are the shape, strength, preparation, and grading of the aggregate.*

**Keywords:** Precast concrete, clay, fly ash, geopolymer, cement replacement, Alumino-silicate binder

## INTRODUCTION

Because it takes a lot of raw materials to make concrete, it makes more pollution than other building materials. When more buildings are built, more cement is needed. When one tonne of Portland cement is made, one tonne of carbon dioxide gas is also made. Greenhouse gases like carbon monoxide and nitrous oxide are made when temperatures reach between 1,400 and 1,500 degrees Celsius and when quarries are destroyed to get materials. Energy requirements call for significant financial investments [1].

Fly ash, clay, and blast furnace slag were all processed so that they would meet these standards [2]. People think that the amount of fly ash that will be made will reach 780 million metric tonnes. This diagram shows how geopolymer cement has changed over time. Recycling ash cuts down on how much it costs to make concrete and get rid of it. Building Geopolymer concrete-made

When alkali hydroxide and alkali silicate are mixed with water, they make geopolymers that can be either amorphous or crystalline. There are different kinds of geopolymer gels, such as alkali activated cement, geocement, alkali-bonded ceramic, inorganic polymer concrete, and hydro ceramic. Geopolymer concrete has both free particles and a paste that holds them together [3]. Geopolymer cement, which came after gypsum and Portland cement, is the most recent innovation in the cement industry (OPC). According to the

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information presented in [1], [1 shows that geopolymer cement Fabrication [2] geopolymers consist of both amorphous alkali aluminosilicates and alkali-activated cements. All types of ash, including fly ash (FA), metakaolin (MK), slag (SG), rice husk ash (RHA), and high calciumwood ash (HCWA), contain aluminosilicates, which, when combined with alkaline solutions, can be polymerized to produce geopolymer concrete. It is necessary for silica (Si) and alumina (Al) to undergo a rapid reaction under basic conditions in order for them to be able to form a three-dimensional polymeric chain consisting of SiAOAAlAO linkages. In contrast to OPC and pozzolanic cements, the compressive strength of geopolymer is achieved through the polycondensation of silica and alumina as well as a high content of alkali.

The compressive strength of OPC is improved by geopolymer as a result of the combination of high levels of alkalinity, polycondensation of silica and alumina, and the formation of calcium silicate hydrates (C-S-H). Geopolymerization and their situation are related in some way [4].

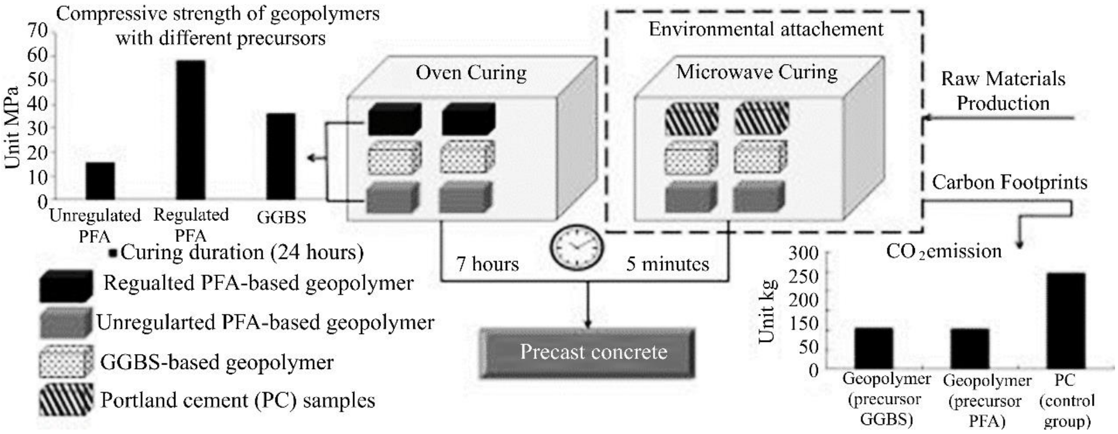


**Figure 1.** Geopolymer cement Fabrication [2].

## GEOPOLYMER CONCRETE PROPERTIES

When geopolymer concrete is cured using dry heat or steam, it gains a lot of strength quickly. Many precast concrete components, including railway sleepers, are made from geopolymer concrete [3]. Figure 2 shows geopolymer concrete materials Because of its strong resistance to chemical assault, geopolymer concrete is often utilised in harsh conditions such as coastal regions with high concentrations of salt and other hostile chemicals. Also, they proved to be very acid-resistant, making them a possible fit for use in environments like those found in mining, some industrial industries, and sewage treatment plants [5].

## GEOPOLYMER CONCRETE MATERIALS

### Fly Ash

One of the byproducts of combustion, fly ash (or flue ash) consists of the particles that are carried aloft by the exhaust gases. Class C fly ash is the only kind that may be used as a partial substitute for Portland cement. The addition of fly ash to concrete can improve its ultimate strength, as well as its resistance to chemicals and length of service life [6]. Utilizing fly ash in concrete production may greatly enhance the material's workability.

Recently, fly ash has been included into geopolymer, wherein the reactivity of the fly ash glasses is exploited to produce a binder with the look and qualities of hydrated [7] Portland cement but likely lower $CO_2$ emissions.

### Clay

Both the fine aggregate and the binder can be partially substituted with clay. Along with other naturally existing geological elements like stones and biological materials like wood, clay is one of the earliest construction materials on Earth. With its high porosity, clay effectively blocks most liquids [8]. Currently, clay is utilised as a binder and a partial replacement for fine aggregate in the building sector.

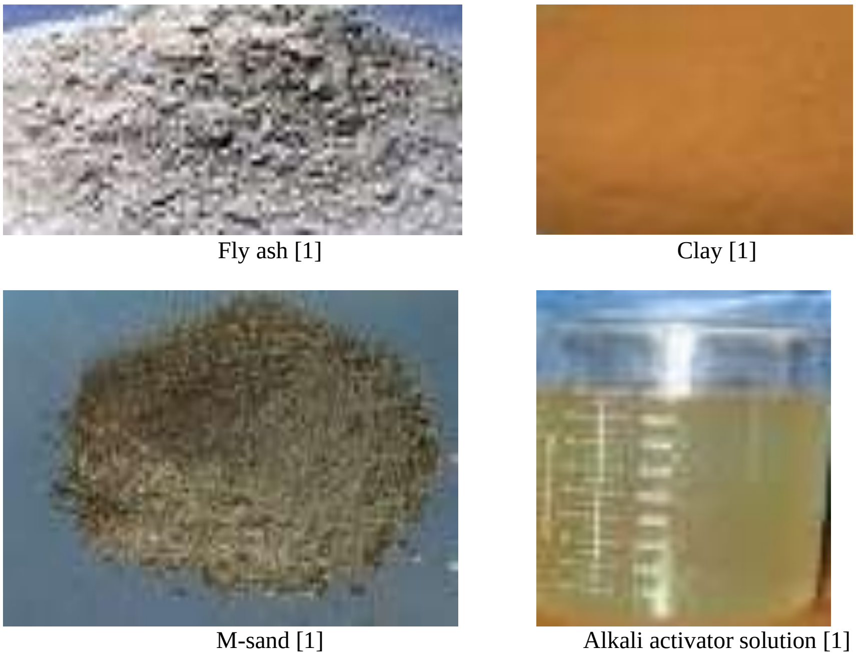

**Figure 2.** Geopolymer concrete materials.

**M-Sand**

In place of river sand, M-Sand is the sole viable option. Groundwater depletion, water shortages, and the insecurity of bridges, dams, and other man-made structures are only some of the environmental disasters that might result from dredging river beds to get river sand [9].

Because M-Sand is pure and there is no waste during production, it may be used to significantly cut down on expenses, similar to how River Sand can be used. Concrete flaws including segregation, bleeding [10], honeycombing, voids, and capillary action may be remedied with the use of M-Sand due to its optimal initial and final setting times and exceptional fineness.

**Alkaline Liquids**

Sodium hydroxide and sodium silicate are used together to create the alkaline liquid needed in geopolymerization. The binder was made by reacting fly ash-clay with an alkaline solution based on sodium. Bulk quantities of sodium silicate solution were acquired from a vendor in the area [11]. The bulk purchase of 97-98% pure sodium hydroxide was made from a regional vendor. This was obtained as either flakes or pellets. Due to the exothermic reaction that occurs when sodium hydroxide is heated, the solution had to be made a day or two before it was used in the concrete mixing [12]. Just before the concrete was mixed, the sodium silicate solution and the sodium hydroxide solution were combined.

## ALKALI ACTIVATION

When the fly ashes are put into an alkaline solution, the Si and Al in them dissolve, as seen in the Figure 3. Involving alkali in the activation of alumino-silicate compounds is a multistep procedure. Strong alkaline conditions cause Si-O-Si bonds to break, which is what happens when alumino-silicate compounds react [13]. When these ties are severed, new phases occur, and their genesis appears to be a process requiring a solution. An important aspect of this reaction is the incorporation of Al atoms into the initial Si-O-Si structure [14]. Gels made of alumino-silicate compounds predominate.

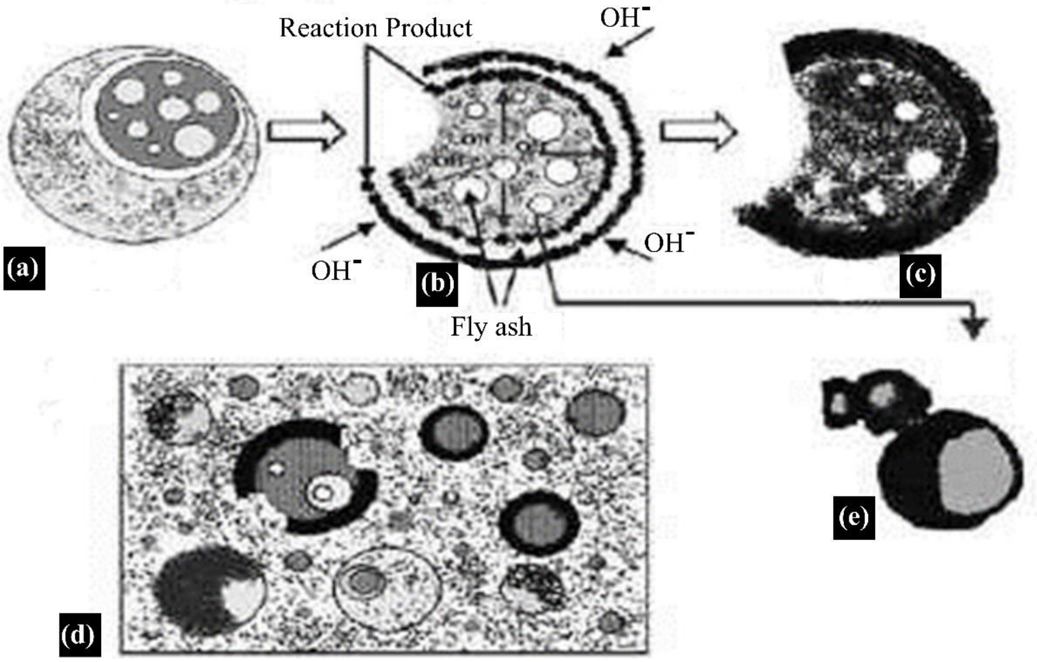

**Figure 3.** Fly ash alkali activation model [3].

**Fly Ash Geopolymer Cement**

When compared to traditional Portland cement concrete, the carbon dioxide emissions from using fly ash geopolymer cement to make structurally sound concrete are significantly lower. In this research, an alkaline activator composed of sodium silicate ($Na_2SiO_3$) and sodium hydroxide (NaOH) was utilised. Sodium hydroxide (NaOH) solution was made by dissolving NaOH pellets in distilled water.

**Geopolymer Sustainability Opportunity**

More and more concrete is being used in building projects all around the world. Typical concrete relies heavily on regular Portland cement for its strength and durability. When one tonne of cement is made, it releases one tonne of carbon dioxide into the air. In addition to being a major consumer of energy, cement manufacturing is also notoriously wasteful in terms of its use of other natural resources.

The concrete industry, in order to contribute to long-term sustainable growth, must investigate possible replacements for Portland cement as a binder [15]. As an alternative, geopolymer made from fly ash and clay can be used. As a cement-free concrete, fly ash-clay based geopolymer produces less carbon dioxide than conventional Portland cement concrete. Furthermore, geopolymer concrete requires less energy to produce than traditional concrete. Fly ash is a byproduct of coal-fired power plants and is produced in large quantities. The use of fly ash, a byproduct of coal-fired power plants [16], as a component of the concrete manufacturing mix.

## GEOPOLYMER CEMENT CONCRETE ADVANTAGES

**Advantages**

Many advantages of using alkali activated geopolymer cement for commercial concrete are summarized below.

***Economic Benefit***

Less expensive clinker manufacturing, which is necessary for Portland cements, is avoided in the making of geopolymer cement. Portland cement manufacture is both expensive and energy-intensive due to the high temperatures (1400–1500°C) required [17].

 

Geopolymer cement's pozzolonic ingredients are plentiful as waste products from the coal power industry.

When these resources are put to use, they alleviate the issue of waste disposal and cut down on the price of making eco-friendly concrete.

### *Environmental Benefit*

Increased carbon dioxide emissions from manufacturing Portland cement contribute to climate change and ozone depletion. In order to make one tonne of Portland cement, one tonne of carbon dioxide is released. So, we need to find replacement binders for concrete [18]. We can lessen the severity of these issues by employing geopolymer concrete. The use of pozzolonic by-products from power plants would also save these potentially harmful elements from being dumped into the environment. As it is, landfills are a major contributor to the threat of metal leaking into groundwater due to the disposal of unclaimed fly ashes and blast furnace slag. An international increase in the manufacture of geopolymer cement might mitigate this danger.

### *Chemical Resistance*

Superior resistance to sulphates and other acids is a hallmark of geopolymer cements. Expansive gypsum and ettringite occur during the degradation of Portland cement, leading to cracking and spalling in the concrete. Since geopolymer materials often have a lower calcium concentration than their parent minerals, they operate better in acidic conditions. There is no gypsum or ettringite production in geopolymer cement, hence there is no sulphate attack mechanism.

## Geopolymer Mortars and Concretes Applications

The commercial potential of geopolymer mortars and concretes is influenced by a number of factors, including their durability, resistance to heat and chemicals, rate of development of mechanical strength, ability to bond to reinforcement and aggregates, and economic benefits as industrial byproducts. The many applications of geopolymer mortar and concrete are listed in the following paragraphs.

### *Concrete Pipes*

Geopolymer concrete's natural resistance to sulphates and acidic chemicals makes it a practical material choice for commercial sewage pipe. Hydrogen sulphide is produced when aerobic bacteria in the sewage system break down organic matter, and it is the primary cause of corrosion and structural damage in traditional sewer systems [19].

The presence of acidic soil in the location of installation also raises concerns about the durability of the concrete. Conventional Portland cement concrete is severely harmed by the acidic sulphate soil's iron sulphides, mineral iron pyrites (FeS2), or sulphide oxidation products and its primary pH level between 1 and 4. To put it simply, concrete and steel infrastructure are severely impacted by the strong acidic conditions formed in acid sulphate soils, and can even lead to structural instability and collapse. Since geopolymer concrete products can tolerate sulphate conditions, they might be employed as a more cost-effective replacement for the materials now in use and the maintenance and repair concerns that come with pipe systems.

### *Structural Elements*

It is certain that concrete will remain a popular building material in the future, since output of Portland cement concrete is rising across the world to keep up with demands for new infrastructure. One reason scientists are looking at geopolymer cement is the hope of making eco-friendly concrete using recycled materials that can compete mechanically and last longer than concrete made with Portland cement [20]. Due to its high compressive strength, low rates of dry shrinkage and creep, and outstanding resistance to sulphate attack and acidic environments, geopolymer concrete are economically viable even when subjected to extreme environmental conditions and heavy operational loads.

 

***Heat Resistant Pavements***

Since geopolymer concrete can retain heat, it may be utilised for heat-resistant pavement. It appears that pozzolon-based geopolymer cements are more structurally stable than Portland cement concrete in the face of high temperatures because they do not breakdown as easily. The quick water loss under high temperatures that causes ageing dry shrinkage and strength degradation is avoided with geopolymer cement because more water is used and stored during particle reactivity.

***Sub-aqueous Seawater Applications***

As it is resistant to sulphate, geopolymer cement may be used in marine environments below the water's surface. Mortars and concrete made with an alkali activated binder are remarkably resistant to the corrosive effects of deionized water, saltwater, sodium sulphate solution, and sulfuric acid. These geopolymers are more durable and resistant to these unfavourable conditions because they are activated with sodium hydroxide, which makes them more crystalline than those made with sodium silicate.

**Durability**

As a result of their low porosity and low thermal conductivity, geopolymer cements can withstand a great deal of pressure from both chemical and heat sources. Issues with the concrete's durability in regular Portland cement are attributable to the high calcium concentration of the major phases [5]. In the presence of Ca $(OH)_2$, C3A interacts with sulphate ions to produce ettringite and gypsum, leading to cement expansion and deterioration into a non-cohesive granular material.

***Acid Resistance***

It has been shown that geopolymers may withstand acidic conditions quite well. For the same amount of time, the maximum loss of test specimens was lower than that of regular Portland cement product. The severity of acid damage is related to the concentration of acid in the immersion solution.

***Chemical Durability***

As opposed to Portland cement-based products, geopolymer materials are resistant to a wide range of harsh conditions without suffering the same surface degradation or other changes [10]. Since geopolymers have a high alkalinity, their matrices tend to be rather dense, which prevents corrosive environments from penetrating them.

***Freezing and Thawing Resistance***

Additionally, geopolymers are unaffected by repeated temperature changes. As a result, geopolymers have shown to be extremely resistant to both heat and cold.

***Sulfate Resistance***

Geopolymer concrete made from low calcium fly ash and clay that has been heated has excellent resistance to sulphate attack. Geopolymer concrete has a lower coefficient of thermal expansion than the more common Portland cement concrete. Additionally, sulphate interaction leads to expansion in Portland cement-based concrete, which accelerates concrete degradation and spalling.

**Heat Resistance**

Alkermanite (rather than the original C-S-H product) forms a microstructure in geopolymer under high heat loading, resulting in improved mechanical and thermal resistance. When subjected to high temperatures, geopolymers do not decompose, lose little weight, and are not combustible.

**Case Studies**

***Cement and Concrete Production***

Anything with a high calcium content can be used in place of limestone as a replacement. Examples include BFS, steel, and cement debris. In 2005, manufacturers all over the world produced a

 

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combined total of 2500 MMT of clinker and 150 MMT of BFS. It is unclear whether or when the general public will be allowed access to these garbage dumps. Switching to cheaper fuels such as petcoke, coal, natural gas, used tyres, waste oil, plastic, waste wood, etc. can help reduce both costs and carbon dioxide emissions. Carbon neutrality does not apply to a large majority of them. They are required to be manufactured from "biodegradable municipal waste" in accordance with EU law [12], which includes things such as paper, animal waste, compost, and garden clippings, among other things. The combustion of fossil fuels results in a number of byproducts, including recycled rubber from old tyres, plastic, and solvents. Even though trash decomposition produces methane, which is a more powerful greenhouse gas than carbon dioxide, burning trash does not count as a sink for greenhouse gases (GHG). Clinker can be partially replaced by two byproducts of the steelmaking process, granulated blast furnace slag and coal fly ash. Clinker can be partially replaced by either of these two byproducts. Because these cements are up to European standards, there is a large market for them. Carbonation is the process by which cement-based materials absorb carbon dioxide from the surrounding air while they are in use as well as after they have been demolished. These effects need to be figured out for each and every construction material that is utilised. There is a direct link between human activity and 10% of all $CO_2$ emissions. A sizeable amount of carbon dioxide is released into the atmosphere during the manufacturing of concrete, which is a typical construction material. The production of cement is responsible for eighty-five percent of these emissions. The transport of both raw materials and finished goods is responsible for 5% of the total $CO_2$ emissions made by human activity around the world. The manufacturing process results in a waste rate of 95%. It is generally accepted that developed nations need to reduce their $CO_2$ emissions by at least two times the level that they were in 1990 by the year 2020 and by four times that amount by the year 2050. The production of concrete will get us to "factor 2," while advances in technology are necessary to get to "factor 4." normal hydration [14] The concrete wouldn't be able to hold its shape without the binder that is Portland cement. The production of clinker involves heating limestone to a temperature of approximately 1,450 degrees Fahrenheit. Other components, in addition to clinker, are essential for the production of cement. The production of cement involves grinding a number of different materials into a powder. When cement is made, approximately 0.92 metric tonnes of carbon dioxide are released into the atmosphere for every tonne of clinker that is produced. The weight of this emission, 0.53 metric tons, can be attributed to the decarbonization of limestone as well as various other fuels used for home heating. The vast majority of the carbon dioxide that is created during the grinding process is then released during the process of producing energy. Because of its importance, the cement industry has been the focus of a great deal of research into the various ways in which carbon dioxide emissions can be decreased and energy productivity can be increased. The production of less clinker and the percentage of cement that is made up of clinker are the primary means by which the $CO_2$ footprint of cement can be decreased when it is used to make concrete. Raw materials, fuels, and the thermal efficiency of the kiln are all contributors to the amount of $CO_2$ that is emitted when clinker is produced.

## Geopolymer vs. OPC Concrete

According to the findings of this study, it is possible to reduce $CO_2$ emissions by utilising geopolymer concrete that is manufactured from fly ash (FA) and ground-based fuel ash. By incorporating sodium silicate into geopolymer concrete, functionality can be imparted to the material. The spillover of pollution has negative effects on the environment. In the manufacturing of sodium silicate, one viable alternative to the use of new cullet is the utilisation of recycled glass cullet. Use of geopolymer concrete, which is produced from industrial waste with an appropriate Si/Al molar ratio and does not have an impact on allocation, should be implemented by the concrete industry in order to meet its targets for the reduction of $CO_2$ emissions. According to the findings of the life cycle analysis (LCA), the geopolymer technology might be useful for recycling waste. There are slags available that contain ferronickel or magnesium-iron and have the potential to be utilised as geopolymeric binders; however, mixed cement prevents this from happening. Because it calls for a relatively low amount of sodium silicate, slag geopolymer concrete is beneficial to the environment. These materials have a smaller footprint on the environment because they do not produce potentially hazardous leachates when they are disposed of. Because MK has a low Si/Al ratio, geopolymer concrete that is based on MK needs to contain a significant amount of sodium silicate in order for it to properly harden. Alternate materials to MK include heated clays with a higher Si-to-Al ratio as well as slag that has been combined with MK before use. Particle technology improves granular dispersion and packing in OPC-based concrete, which in turn results in a reduction in the amount of active binder that is required. The process of geopolymerization has the potential to produce "green" concrete and other construction materials that reduce carbon emissions. This is a potentially exciting development. Without first conducting a Life Cycle Assessment (LCA), it is impossible to provide an accurate assessment of the impact that geopolymers and their byproducts have on the environment. Figure 4 illustrates a streamlined version of the system's life cycle.

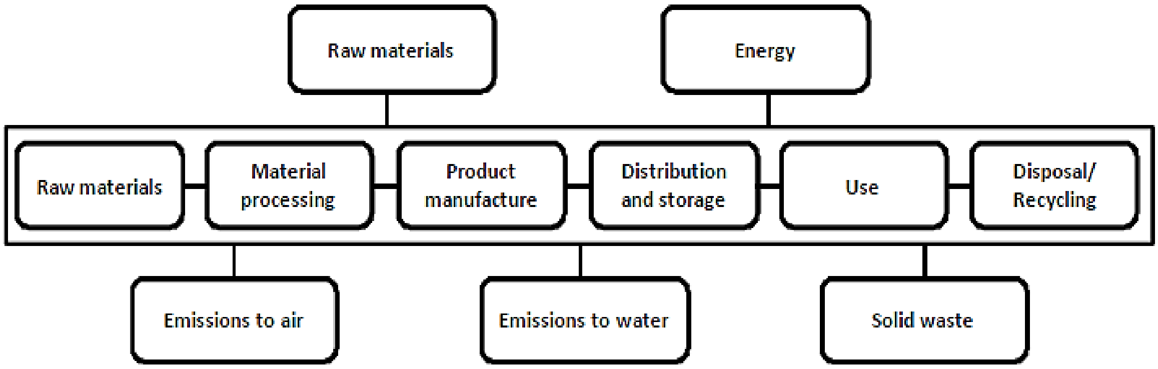


**Figure 4.** Life cycle system [16].

From what little research there is available, it appears that the creation of most common varieties of geopolymer concrete has a less carbon footprint than that of common OPC concrete. Using the LCA approach, we compared two geopolymer mix-designs across a number of environmental effect areas (global warming, energy and resource depletion). In depth LCA-based evaluation of the environmental impact of making geopolymer concrete was completed recently.

## DISCUSSION

The provision of a high standard of living while simultaneously satisfying fundamental requirements ought to be the objective of any future sustainable city. Even if we don't know what people will need in the future, how good their lives will be, or what "sustainability" means, it will still be important to develop new materials that have a smaller carbon footprint and adhere to the "zero waste" principle. The "Thematic Strategy on the Prevention and Recycling of Waste" developed by the European Union (EU) lays out in detail plans for the management of energy supplies as well as waste. As the example of Lead Market demonstrates, there is an immediate need for new methods to make recycling effective. The Waste Framework Directive puts trash at the top of the priority list and mandates stricter recycling, reusing, and recovery goals. If "lifecycle thinking" is unable to provide sufficient evidence to support a shift in the priorities of the waste hierarchy, then preventing waste, finding new uses for waste, and recycling materials will continue to be prioritised. There is waste from both industrial processes and construction projects included. Any brand-new product must be in compliance with international standards. The construction process involves a number of intertwined aspects, including the design, the materials, the natural resources, as well as the social, economic, governmental, and administrative factors. The construction industry has the highest overall consumption of materials, measured in terms of mass. Because consumption of cement in Europe has remained relatively constant over the long term, the price of new aggregate is likely to rise.

Because of how much power it uses, the built environment is the source of the majority of emissions that contribute to global warming. The vast majority of landfills in Europe are stuffed with

 

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debris that can be recycled from construction and demolition projects. Monitoring a building's consumption of resources, air quality, water consumption, and energy production can help reduce the adverse effects a structure has on the surrounding environment. We have a pressing need for more materials that are friendly to the environment. Materials are considered to be eco-friendly if they do not cause any harm to the surrounding environment in any way, including through their decomposition, durability, recycling, or toxicity. The levels of ozone found indoors are typically higher than those found outside, but these levels can be lowered with the assistance of environmentally friendly materials. Academics and successful businesspeople have been debating for a very long time whether or not it is worthwhile to invest money in environmentally friendly building practices. Many professionals are still put off by the high initial costs associated with adopting environmentally friendly practices, despite the fact that academics are confident that the majority of environmentally friendly buildings can be built at a low additional cost. It is necessary for researchers and practitioners to communicate their findings and insights with one another in order to effectively apply newly discovered knowledge in the process of addressing the issues mentioned above. The European Spatial Development Perspective promotes the concept of the "compact city," also known as the "city of short distances," as a way to improve the coordination of land use, transportation, and day-to-day activities. Higher population densities and a greater variety of land uses lead to lower levels of both emissions and energy consumption. Undoubtedly, it is extremely important that this pattern remains unchanged. In contrast to Portland cement, the majority of geopolymer systems use binding agents that are derived from naturally occurring minerals and the waste products of industrial processes. The end result is a reduction in both energy consumption and emissions of carbon dioxide. If we want the city of the future to have less of an effect on the surrounding natural environment, the technology that will be used to construct it will need to be upgraded and made more friendly to business.

## CONCLUSION

- Geopolymers' major components, fly ash and clay, are industrial by-products, making their production cheap.
  Since geopolymer cements are produced without the release of damaging greenhouse gases, they are regarded to be ecologically benign. Unlike Portland cement-based materials, geopolymers don't need lengthy curing times.
- Ettringite and gypsum, which can lead to cracking and degradation, are not formed thanks to geopolymer's resistance with sulphate and acidic conditions.
- Substituting the admixtures presented in this study for natural river sand results in improved strength metrics for Geopolymer Concrete.
- Geoplymer concrete, with properties matching those attained by this high level of polymerization at a 40% replacement rate, is an option. However, as the w/c ratio increased, the transition zone between the geopolymer and the cement paste did not form properly. Hydrotalcite's space-filling ability boosts hydrates' initial compressive strength.
- In high-temperature situations, hardened geopolymer materials function well because they resist heat transfer to a large degree. There is almost no loss in mass during the reaction because geopolymers retain most of their moisture.

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