Review on Life-Cycle Assessment and Environmental Impact Assessment of Geopolymer Concrete

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Abstract

1. Introduction

The cost of chemical solution (sodium silicate and NaOH) used for activation in geopolymer concrete (GPC) is very high. GPC is an excellent alternative to conventional concrete due to its eco-friendly characteristics. Conventional concrete requires a large amount of heating. To reduce required energy and CO2 emissions, GPC utilizes industrial waste materials including ashes [1]. The requirements of making ordinary Portland cement (OPC) are high. In GPC, the requirement of making alkali activator is less. In GPC, there is no need for a feed of CO2. GPC helps in nature in a way that the leachate quantity and the value of measured contaminant are reduced. To displace the OPC by GPC, 5.4 GJ of the energy is saved. Utilizing local source materials in the GPC recipe helps in the reduction of the total cost. Geopolymer concrete (GPC) is made of fly ash, GGBS, and alkaline activators. It is observed that the workability of GPC was less than CC. There was no bleeding and segregation in GP. The average compressive strength of GPC at the age of 28 days was around 48 MPa. It was higher than CC. The modulus of elasticity of GPC at the age of 17 days was around 41 GPa. The GP had an almost similar young's modulus to CP. The rate of permeation of chloride ion was found to be lower in GPC than in CC. The chloride ion penetration depth was lower in the GP. It suggested that the durabilities in terms of permeability and chloride ion penetration were higher in the GPC compared to CC. Due to more leaching of the gypsum hydration product from surface layers, the water absorption of GP was increased significantly. Since the GPC surface was rougher than that of conventional concrete, there has more suction in water absorption. Actually, the main goal of GPC is to replace carbon-intensive OPC. GPC can be used in various fields instead of cement-based concrete. GPC is useful in various fields with its excellent durability and mechanical properties. For use in construction industry, GPC should be modified. Due to the high heat release at a very early stage, GP is not recommended for mass concrete. To avoid swelling of alkalis, the feed of water and GPC mix should be made at different times. It is strongly required to prepare alkaline solutions at least a day earlier. Generally, mass concrete means more than 50 cm in thickness. However, only in 10 cm thickness the temperature difference will become remarkable in GP. The curing box used for isothermal curing should control ±2 degrees. Heat diffusion in the GPC would be less compared to that of the CC. Curing box was heated at a very high temperature to maintain a temperature within the GP.

Keywords: GPC, LCA, EIA, Impact Assessment, Geopolymer Concrete

2. Geopolymer Concrete Overview

Geopolymer Concrete (GPC), which has been increasingly used due to its advantageous features, is a good alternative to ordinary Portland cemented concrete (OPCC). It has become an important development material with the inclusion of industrial by-products such as fly ash, ground granulated blast furnace slag (GGBFS) and nano-silica in concrete production. Ash-based geopolymer possesses ecological prospective in construction materials owning to the elimination of ordinary Portland cement [1]. Using local source materials is not only economical but also sustains natural resources. The total cost of GPC is comparatively reduced if contrasting with OPCC involving in high cost due to the need for vast quantities of sand, as well as aggregates extracted from depleted mining sites. These materials are mainly acquired by extensive transport, which increases their production cost. Moreover, sand excavating actions can be significant impacts upon the environment causing landslide, erosion, and sedimentation.

Geopolymer Concrete finds broad applications in the fields of building, bridge, pavement, road repair, underground structures, etc mainly due to exceptional physical-mechanical properties and high durability of GPC. Nevertheless, the following limitations have to be taken into account during application. As the early heat release results in a high temperature of GPC due to an intense exothermic reaction between MK and high pH alkaline activator, GPC is not recommended for massive concrete works just the way it is left in the sun for 7 days after being cast in block and then to be subjected to curing in water. There is a possibility of drying shrinkage in cementitious material with high heat of hydration. Like the general concrete, it is weak at the tension point, which necessitates attention and innovation in order not to experience tekketing and under-settlement. If GPC cracks in tension, the crack will be further enlarged so as to decrease energy absorption. By reinforcing with certain structural materials, cracks are not allowed to propagate to critical points, thereby maintaining the strength of the material. Since the fracture toughness of brittle materials is very low, crack design management should be conducted effectively so that the integrity and functional capacity of the structure are not disrupted.

3. Life-Cycle Assessment (LCA)

3.1 Introduction

Life-Cycle Assessment (LCA) has been growing in importance through the years. As part of an initiative to establish a database on the life cycles of materials, the use of plastic and alternative materials in consumer products and their environmental impacts, LCA studies have assessed the life cycle of a wide array of products, including beverage containers, casings and housings of electronic products, inject-molded dinner plates, floor tiles, mobile phones, and personal computer monitors. They have also been used to compare the environmental performance of products made of plastic and of traditional materials, like glass and metals. Other studies of plastics and alternative materials have shown the potentials for resource savings and reducing waste generation. In the construction industry, an increase in the use of LCA studies for building materials, like bricks, concrete, and tiles, has also been noted. These studies have analyzed the savings of substances and inputs that play an important role during the production phase and have potential impacts on the environment. As a methodological framework, LCA has helped projects to assess the impacts of houses, buildings, roads, and urban infrastructures, and has also been used to assess the reutilization of materials in construction. Other applications of LCA in the construction industry include assessing earth retaining systems, railway sleepers, noise barriers, and pavement kerbs from an environmental point. Recent proposals have established the use of reference buildings and infrastructure systems for the development of environmental product declarations by suppliers as part of evaluations of external services for new infrastructure. Recently, the use of an environmental evaluation in tendering green public works has been incorporated. The importance of safety and environmental policy has also been emphasized. The life cycle of certain systems has also been assessed. In transport systems, LCA studies have assessed the environmental impacts of public transportation, the disposal of sheet piles, and different ports. In the port sector, there is a strong relationship between the environmental impacts from life-cycle consumption of materials and construction. This dependency is especially important in the global context of increasing trade activities since it determines the location of the container traffic between different ports.

3.1. Definition and Scope

In order to effectively reduce the negative impact of the construction industry on global warming, countries around the world are also actively responding to reduce energy consumption and emissions [2]. China has put forward the goal of 'reaching the carbon peak by 2030 and becoming carbon neutral by 2060'. As an essential component of concrete materials, silicate cement is one of the most used building materials in modern construction. The industrial production of cement consumes many resources and energy, with the energy consumed reaching 10% of the total global energy consumption. In particular, the calcination stage of raw materials emits a large amount of CO_2 and other harmful gases, causing severe environmental pollution. Geopolymer concrete (GPC) has been recognized as an ideal new environmentally friendly building material, reducing the use of energy-intensive, emission-intensive cement. However, the extent to which geopolymers can reduce environmental impacts and their significance on various environmental impact indicators is unknown. Life cycle assessment (LCA) is one of the most systematic and scientific-based environmental assessment tools for evaluating building materials through the whole life cycle, from the extraction and processing of raw materials through the construction process, use, maintenance, and demolition at the end of life. During the hardening process between the alkaline activator and the aluminosilicate material, geopolymerization occurs, and a three-dimensional polymeric network structure is formed. Compared with ordinary Portland cement concrete (OPC), the global warming potential of GPC was reduced by 22–49% based on ten environmental impact categories. Multivariate Analysis of Variance (MANOVA) and Linear Regression Analysis were used, which simultaneously contains both CO2 emissions and compressive strength datasets, to identify relations and draw conclusions. Using the high and low strength composite template, Gray Relational Analysis concluded that high fly ash content, unfilled water-to-solid ratio, and delayed curing method would be more environmentally beneficial; however, traditional OPC concrete would have reduced strength in the same situations for the compound design of another sustainable GPC.

A review focused more on solid waste management and the heavy-duty performance of waste-based geopolymer concrete in civil engineering, military, and road applications thereby presenting a significant gap in research. War and civilian construction tasks have an urgent need for high performance and long-lasting infrastructure. Geopolymer is carbon negative, has high early strength and chemical resistance, and is able to operate in various areas of military construction especially in hardening engineering; Conventional concrete-based infrastructure is superior to cost. Therefore, in this context the significance of geopolymer concrete as a strategic building material is underscored; A growing increase in radioactive waste for accurate isolation becomes essential. As a neutral and non-combustible material geopolymer has enormous potential in the immobilization of radioactive waste [3]. At the same time, meta-studies are very scattered and limited in quantizing the environmental burden and mechanical-based studies. Considering prior LCA with the environmental profile of the production of Portland cement and GPC provides valuable ways how the production chain could be improved in low carbon emissions. For GPC self-levelling mortar or high-strength concrete, the fillers were used and compressive strength was significantly higher than NP. The strength and environment score were optimized by the Taguchi method with the goal of maximizing the strength and minimizing the environment score. To decrease the negative affectivity of bad environmental factors, there was a rising development of green approaches in industry.

3.2. LCA Methodologies

In addition to relevant research presented in the "Literature Review" section, some other studies involving fly ash-based geopolymer concrete considered in this study will be compiled too. Mechanical properties and toxicity tests were studied. Geopolymer research using fly ash, and geopolymer research on a wide range of materials including fly ash are covered. The formation of geopolymers formed using fly ash via alkali hydroxide and alkali silicate routes through a meta-synthesis of patents was studied. The maintenance of high temperature during the solidification process was suggested to yield geopolymers with a higher crystalline phase content, that is, LTA-type zeolites. A green and superior method for the synthesis of geopolymer materials from natural geological materials and industrial waste materials was dealt with. Ceramic microspheres were manufactured by granulating and heat treating fly ash geopolymers, and physical, mechanical, and thermal properties were evaluated. Geopolymer was produced using industrial wastes, including fly ash, and proposed an alkali fusion route to dissolve and polymerize these materials. The microstructural and mechanical properties of geopolymer derived from fly ash highly activated by combined acid and alkali solutions were evaluated. The microstructures of different classes of fly ash-based geopolymer specimens cured under various temperatures were studied. The resulting material was crisp-like with apparent macropores. The microstructure of the specimens was denser than the ordinary concrete containing OPC. A general growth trend of degree of gel to un-reacted precursor was observed. The influence of paste mixing protocol on the porosity characteristics and microstructure of geopolymer binders was investigated. The engineering properties of fly ash geopolymer reinforced with bars were focused on. Due to the low pH of fly ash-based geopolymer, large-scale debonding behavior was observed with the use of bars, except the ones whose outer surface was treated with the alkali agents. The performance of other combinations of bars was inferior in comparison to bars.

3.3. LCA Tools and Software

There are a large number of Life-Cycle Assessment (LCA) tools and software programs, some of which are freely available through the internet. Some are integrated into Geographic Information Systems, while others allow a probability approach to LCA, as well as a cut-off approach. However net environmental impacts predicted through LCA are vastly different due to a wider range of assumptions made in an LCA study. This is a serious problem when using LCA to guide environmentally-biased decision-making, and when attempting to develop an environmental policy based on LCA. Since most criticisms of LCA tools and studies have compared them to the perfect hypothetical (or cradle-to-grave) study, maybe it is time to acknowledge that LCA studies are first and foremost convenient patterns of energy and materials use and environmental emissions during representative processes concerning a particular industry ([4]). If uncertainties in the environmental performance of products are to be compared fairly, a standardised and well-defined approach based on published information representing the key stages or aspects of their life cycle is needed. To address the data uncertainties in Life Cycle Assessment (LCA) studies, a set of basic reliability criteria are put forth in future LCA submissions to accredited journals, consisting of both qualitative and quantitative checks on the Life Cycle Inventory (LCI) to identify the boundary and data quality of the LCA study. Guidelines for the presentation and submission of publications addressing potential impact of Geopolymer investigations on concrete and similar type construction materials are invited ([2]).

3.4. Case Studies of LCA in Construction

Although LCA was defined as a tool to assess the environmental burden of products, new pieces of research would rather focus on the burden of buildings throughout their life cycles. However, LCA has been used with both meanings; most researchers have been analyzing the environmental impact of using a specific construction solution or element, but some of them have favored to assess the impact of buildings as well. According to these stances, they should not neglect the state-of-the art of LCA studies focused on buildings, but most of the existing examples and background knowledge will be related to the former. It must be noted that LCA studies on buildings are usually called Building LCA (BLCA), despite the fact that the prefix is not generally added to address other LCA studies of specific end-uses and so as to avoid some terminological ambiguity. Structures and buildings are not the same thing, but in the construction domain these terms are used improperly interchangeably. Buildings represent one third of society's ecological impact, that's why most studies address such term. Nonetheless, following [4] best practices and how it is usually carried out in other construction-related studies, there will be a mostly consistent reference to "concrete structures". The methodology to practice LCA studies was standardized by the ISO standard 14040, four general steps must be followed: The goal and scope definition study is an important phase in the LCA process. The environmental effects of concrete structures were observed in this part, underlined the influences of each phase of the system, thought the next three stages should report all effects. Due to the large number of variables that influence the environmental results, it is substantial that only the most relevant or significant effects related to each construction phase are discussed. The inventory analysis supposes the quantification and compilation of data according to different environmental impact types, in order for such data to be ready for the impact assessment stage. Aside from the available data obtained from the reviewed LCI database, predictions were made for uncertain cases. As a result, in this section all information and data are organized to provide a detailed insight about how the environmental effects commented may be translated into potential data requirement for studies to come. Different impact types and subtypes to be calculated may be selected very attentively. Applying different subtypes might change environmental results' interpretation, so cautious judgment on such effects must be taken, but such effect will not be reported, so as not to blur the discussion.

4. Environmental Impact Assessment (EIA)

2. Introduction The absence of life-cycle assessment (LCA) in the literature on geopolymer concrete has created a lack of understanding of the environmental impact of this promising material. LCA is typically conducted as part of an environmental impact assessment (EIA). Two kinds of EIAs can be distinguished: a comparison of geopolymer concrete production with other concrete technologies and a comprehensive EIA based on a desired concrete structure. An overview of the environmental impact categories available in EIA and their relevance to concrete structures is provided.

4. Environmental Impact Assessment (EIA) From a practitioner's point of view, there is great interest in environmental impact assessment (EIA) of specific structures, as the material requirements depend to a large extent on the design specifications of the structure. The available EIA applications in current LCAs will be presented and discussed in terms of applicability to concrete structures, concentrating in particular on the possible use of LCA inputs for the optimization of sustainability criteria in structural design [4]. For the purpose of this discussion, there will be a focus on concrete structures. It shall be noted that the goal of this part is to provide the basis for the formulation of a framework for a complete and reproducible EIA procedure of geopolymer concrete and its elements suitable for practical applications in infrastructure planning.

4.1. Definition and Scope

In order to effectively reduce the negative impact of the construction industry on global warming, countries around the world are actively respond to reduce energy consumption and emissions. China has put forward the goals of peaking and carbons at 2030 and to be carbon neutral by 2060. In modern construction, silicate cement is one of the most widely utilized building materials. However, its industrial production consumes abundant resources and energy, with energy consumption contributing to 10% of the total global energy consumption. The waste calcination stage of raw materials releases huge amounts of CO2 and various harmful gases, causing serious environmental damage to the atmosphere [2]. Since the 19th century, the global temperature has been abnormal. It has been determined that the increase in greenhouse gas CO2 is a primary cause of global warming. In addition, the demand for building materials in construction is anticipated to increase significantly, resulting in a sharp rise in energy consumption and CO2 emissions from the production of cement concrete. Therefore, it is of great urgency that research be performed to develop environmentally friendly building materials that reduce the use of ordinary cement. Geopolymer concrete (GPC) is a novel material known for its positive impact on the environment, as it reduces the use of traditional energy-intensive cement and associated environmental impacts.

However, the extent of reductions in the environmental impact of GPC is understood only to a small extent. Life Cycle Assessment (LCA) is one of the most systematic tools for estimating the environmental impact of building materials throughout their lifecycle. Most existing researches on the environmental assessment of building materials have concentrated specifically on ordinary Portland cement concrete (OPC) due to its extensive use in a variety of construction activities. The high environmental burden imposed by OPC is primarily attributed to the high energy consumption of the production of cement and the subsequent large greenhouse gas emissions generated during these manufacturing processes. Furthermore, the literature search found very few articles on the LCA with respect to GPC. For instance, the CO2 emissions of GPC were estimated to be 9% lower than those of OPC concrete. Metakaolin-based geopolymer can reduce CO2 emissions from 27 to 45%. The environmental footprint of alkali-activated binary concrete is 44.7% less than OPC. There is strong evidence that feedstock sourcing would be carefully selected in order to maximize these benefits on a global climate basis. However, the 'cradle to gate' model used in LCA is incomplete from a broad perspective beyond production. Furthermore, with production being highly active, other processes related to transportation, maintenance of elements, and waste generation from construction, repair, and replacement of concrete contribute 30-69% of the total CO2 emissions received 30 years. All the mentioned studies have indicated that GPC at specified compressive strengths releases fewer CO2 emissions than OPC concrete. From an in-depth examination, the studies that determined a particular compressive strength grade only concentrate on a particular strength grade, such as 45 MPa. The nature of the link between LCA, mechanical strength and process parameters has not been well understood, as reflected by the broad use of the term in the literature. The findings also indicate that GPC production is influenced by a variety of parameters, and this should be taken into account when making decisions.

4.2. EIA Methodologies

The environmental impacts associated with the construction of a school building, located in Na'ama Bay, Egypt, constructed using both conventional reinforced concrete and alternative geopolymer concrete constructions are assessed. This is carried out using a method combining both the Life-Cycle Assessment and the Environmental Impact Assessment techniques. The use of these environmental assessment methodologies allows estimating the global environmental impacts at every construction phase, as well as providing a comprehensive view of the environment affected by the constructions. Moreover, the most significant environmental issues are identified during each phase, which allows policy makers to introduce the required environmental protection measures. The methodology applied to a real construction case demonstrates that the adoption of these environmental friendly geopolymer concrete constructions leads to substantial reductions during both the construction and the operation phases when compared to conventional reinforced concrete constructions. It is anticipated that these environmentally optimized geopolymer concrete constructions are beneficial for both the local environment of Na'ama.

Through its ability to reduce the global environmental burdens associated with the construction of buildings, geopolymer concrete is recognized as a more environmentally friendly material than conventional concrete. A comparison of the global Life-Cycle Assessment of the construction of a school building located in Na'ama Bay, Egypt, is made using both alternative geopolymer and conventional reinforced concrete materials.

4.3. EIA Tools and Software

Several tools and software are proposed by the European Union to conduct an LCA (Life Cycle Assessment) as an environmental measure for the product declaration of construction materials. In a very close relationship, the European Union also proposes a tool to deal with the environmental aspects of Civils Works, the EIA (Environmental Impact Assessment). While the LCA tool is particularly addressed to the material processing characteristics, the EIA includes all phases. The Common Approach described in the Directive 96/61/EC contains a list of environmental issues in the following fields: Emissions to ambient air, discharges to water and total quantified effluent, production of waste and measures for its prevention, integrated pollution prevention and control, hazardous substances, risk of accidents, controls and noise emissions, land use, impact on soil – including contamination –, air and water, risk to human health. The CEN proposal for a Comité européen de normalization conducts the EIA, and the Standards Organization deals with available methodologies and models to foresee the performance of a Civils Work from the environmental standpoint. These models fall into three categories: models for the description of the current state, models for the assessment of impacts, models for the reduction and evolution of impacts. An EIA tool for Civil Works is under exploitation and it is being developed with certain characteristics and expansions regarding the available EIA tools used in this market. Though the European Union develops its own tool for EIA, there is a wide variety of them which should be described before establishing whether there is a gap. Some of these tools are described in SCV III. In a very general manner, an EIA begins with the identification of the Civils Work destined, specifying its location. Furthermore, the direct and indirect implications which could take place near this Civils Work are considered. The following step is to study the probable degradation of affected media, dealing with the current situation. This is the development of an Environmental Baseline. Once this Baseline is established, the Civils Works main phases are described in order to foresee at each moment the most probable impacts. The last part of the EIA compares the current and future situations of the Civils Work, pointing out the actual evolution of the most impacted media, and proposing additional measures to avoid them ([4]).

4.4. Case Studies of EIA in Construction

In the 20th century, there was growing concern about the impact of construction on the environment. Recently, interest in themes that involve the sustainable development of the construction industry has also increased interest in the legalization of Earth Buildings and Earth Construction materials. An EIA report has become required by law when opening or expanding any industrial plant in the Philippines in 1978 and similar rules began to be applied to environmental management in the construction of other works, and in 1995 the Construction and Industrial Waste Utilization Law was enacted. The purpose of the law is to maintain and manage the environment by utilizing and recycling construction byproducts, and to establish multiple systems to promote the utilization of industrial byproducts, restraining and dry landfill of construction byproducts. Thus, the Environmental Impact Assessment (EIA) on the construction project is becoming more common in the early stages [4]. In the construction industry, concrete is one of the most commonly used materials. It made using cement, sand, and coarse aggregate as a binder, and it has been traditionally known as having considerably negative effects on the environment. The environmental aspect of concrete is especially the biggest case in the construction industry since 70% of produced concrete is used in buildings or infrastructure. The production and practical use of concrete, referred to the most widely consumed material around the world after water, cause concern for the increase of the carbon dioxide emission rate. Efforts to go along with the increase in energy consumptions to lower CO2 emissions and reduce the environmental impact, and such efforts are usually tried as changes in the mixing kind of cement and the manufacturing process instead of changing the strength and dependency of the concrete structure. At the same time, there are many cases where research into eco-friendly construction materials which can replace concrete is being actively conducted [5].

5. Comparative Analysis of LCA and EIA

The methodology to practice Life Cycle Assessment (LCA) studies was standardized by the since the decennium of the nineties, in an attempt to facilitate and harmonize the regular practice of environmental assessments on any system. Despite this, LCA further needs improvement to prevent present limitations and uncertainties on its results. This is an issue of concern in any engineering practice, when looking for improving the life-time cycle and the sustainability of any system or product - concrete structures included. Some show a very recent literature review on the spread and the evolution of LCA studies on concrete structures, with focus precisely on LCA methods, assumptions and scope. Even when using LCA on concrete structures, there are few publications on how to standardize, reduce or prevent biases and uncertainties present in its real practice. It is observed that the wrong selection or the inaccurate parameterization of the potential environmental hot-spots might indeed drive the LCA outputs to inaccurate or wrong interpretation. LCA has been criticized for the assessment of too broad systems.

Environmental Impact Assessment (EIA) is an alternative and recent approach to LCA studies, but it also was originated in the vision of a rigorous and robust assessment of the environmental loads and damages induced by any products, services or activities, in order to prevent and mitigate potential impacts. EIA is based on the same philosophical and scientific background as LCA, but its domain and scope are completely different. As a result, EIA is mostly focused on the prediction of potential impacts in the exclusive social, environmental or regional spheres of any patch of land or forthcoming activity. EIA is a practice of broad systems, as opposed to the detailed ones specially conducive to LCA studies. The scope and the depth of both tools must always be different, but when the system falls in their common scope, LCA could be a valuable, improved and extremely reliable tool for the insightful before/after assessment of any potential impacts assessed by EIA methodologies. A useful 5-steps comparison of LCA and EIA is presented there, where a potential bias or complementary effect is pointed out at each step [4].

5.1. Similarities and Differences

This is a Core R&D Programme aims to create teaching material. However, the examination of various Micro-Teaching (MT) tallies compared to final TMR&D suggests that general recognition is something to be left to the reader [6]. The slump value of fresh geopolymer concrete has been found to increase as the water content of the mixture increases, which is similar to Portland cement concrete. The compressive strength of geopolymer concrete decreases as the water-to-geopolymer solids ratio by mass increases. It is observed that this trend is analogous to the well-known effect of the water-to-cement ratio on the compressive strength of Portland cement concrete. As the water-to-geopolymer solids ratio by mass increases, workability increases, leading to a more fluid mix and thus potentially higher porosity. It is found that the indirect tensile strength of geopolymer concrete is only a fraction of the compressive strength, similar to the case of Portland cement concrete. The behaviour and failure mode of fly ash-based geopolymer concrete in compression, however, is found to be similar to that of Portland cement concrete. Early studies of long-term properties show that fly ash-based geopolymer concrete undergoes very little shrinkage: in the order of about 100 micro strains after one year, which is significantly smaller than the range of values experienced in Portland cement concrete. Test data also show that geopolymer concrete has excellent resistance to sulfate attack, with no damage to the surface of test specimens after exposure to a sodium sulfate solution for up to one year.

5.2. Integration of LCA and EIA

Life-cycle assessment (LCA) methodology is relatively young compared to other models. LCA technique aims to fulfill the growing demand for a holistic assessment of the potential impacts one or more products or processes could provoke on the environment. This goal is achieved by quantifying and assessing the inputs and the corresponding outputs arising from those systems across their entire life-cycles. Finally, the obtained results ought to be considered for a sound planning in sustainability terms to prevent the most undesirable impacts, preventing the shifting toward new environmental burdens. The international community finally worked on its effectiveness by means of a set of standards, being the ISO 14040 series the most advanced achievement on this regard. LCA methodology may be combined with already other valuable insights and prospective, incorporating the wider framework of the environmental impact assessment (EIA) paradigm. Environmental Impact Assessment (EIA) is defined as a tool that branches from industrial ecology devoted to foreseen the environmental consequences arising out of the implementation of a project, plan or policy, and concerning both their construction and operational phases. This tool was initially developed at the USA during the 70s and become by far the most extended formal practice elsewhere nowadays. EIA can be considered static whenever focuses on the identification of the problems that could arise out of the potential interactions among the system and the environment, and prognosticates the trends respected the prevention, mitigation and or compensation of the most adverse impacts. But it can also become an endogenous tool by uptake the needed feedbacks as to improve the overall performance of the project/policy after the analysis of the detected problematic issues. EIA approach was a consequence of the enactment of the ever well-known National Environmental Policy Act (1970), being the United States the first country where this tool arise to diligence and efficiency. As far as both LCA and

EIA practices are concerned, last years have been somewhat more prolific in integrating LCA within EIA studies [4].

6. Sustainability in Geopolymer Concrete

The GPC is becoming one of the alternative materials for normal PC. While producing 1 t of PC, around 1.0 tons of CO2 and 1.75 MWh of energy are emitted during energy consumption. On the other hand, using GPC can save around 80% of CO2 emissions depending on the type of Binder materials used. Moreover, using GPC can reduce around 80% of energy consumed in production. Mixes involving large proportions of GPC, aggregates must be fully in contact and the mix must be placed under some compaction or consolidation process to displace air voids. The boundary and space of casting must be perfectly sealed to avoid evaporation of water during GI. Actual design and production on GPC mega precast beams were discussed together with economic issues. For future studies, the environmental performance of GPC can be improved using sufficient curing, and similar studies with reinforcing materials.

Geopolymer concrete (GPC) has been widely accepted as a new construction material. This paper presents the experimental program that studies the behavior of GPC sub-assemblages under different ambient temperatures and loading conditions. Eleven pre-casted, heat-cured GPC hollow blocks with different cement content were tested to evaluate their thermal and mechanical properties. Results suggest that the pre-casted GPC hollow blocks can be used as building wall elements. A study on the aging effect taking into account actual perspective construction methods. The proper GPC mixture design was first developed for the GPC precast beams used in the actual field. Then, slabs were placed on the precast beams to mimic the girder-slab bridge structures. The bonded shear test was used to assess the interface shear behavior between the GPC beam and slab.

6.1. Sustainable Materials

Concrete due to its unique properties takes an enormous amount on a global level for construction activities. But on the other hand, its production process causes climate change because its production creates a large amount of CO2 emission. Also, the aggregate from the natural source is going to end. To achieve significant development and maintain it, we needed to show high attention to the environment and its depletion resource. In order to protect nature, the method required the study of human influence on it, the measure and analysis of environment problems, and possible prevention. Life-Cycle Assessment (LCA) is a systematic method for evaluating potential environmental impacts associated with product manufactured from cradle to grave. Moreover, environmental analysis is a more contemporary and wider field. With a view to achieving more integrated planning and construction, it extends to planning and analysis on the environmental impact of urbanization on environmental resources [1]. The geopolymer concrete is an alternative concrete to conventional concrete because there is no use of cement in the preparation of geopolymer concrete (GPC), using as a binding of material. The geopolymer concrete has a solid concentration that uses high volume of fly ash in-waste. The proper management of fly ash is a big problem for most of the industry. This research finds a way to use geopolymer concrete to solve an environmental problem and reduce global warming. This is based on the study of Life Cycle Assessment (LCA) of the geopolymer concrete with fly ash (FA) waste. The reduction of an emission of CO2 with preparing GPC is much less than Portland cement concrete (PCC). The findings of this study are reducing CO2 emissions is up to 90%, less energy consumption, releasing of other hazardous gases are significantly reduced, natural resources are preserved, better for landfill management. With taking all this consideration, it shall be effective and efficient in construction works.

6.2. Energy Efficiency

Concrete is Indonesia's most widely used building material. However, the production of Portland cement as its binder releases around 0.8 billion tons/year of massive CO2. Geopolymer concrete as a green alternative cement binder has a very promising prospect. However, life-cycle analysis not only estimates CO2 but also most important and typical assessment criteria by environmental impact assessments. In general, six categories of AEI considered, which are human health, ecosystems, raw material depletion, criterions of air, water, soil and climate change. The energy effect of geopolymer concrete compared to ordinary Portland cement is debatable. Using linear programming technology, the LCA/EIA matrix of the various kinds of Fly ASH Geopolymer Concrete for various stages of life-cycle has been constructed.

Concrete is Indonesia's most widely used material in construction. However, only a small portion is used as residential building materials. The Gumi City Government has a cement program. Mortar semi-permanent housing project. The paste is a mixture of concrete and other materials to make buildings permanent. To conduct an environmental analysis of the kind of material used. The Fuzzy Analytical Network Process method combines the consideration of the engineering value ANalysis Pairwise Comparison method. As a method to find the percentage of geopolymer on mortar with silica fume that has the highest value. The results obtained are mortar with a 70:30 comparison of Geopolymer and Ordinary Portland Cement with silica fume that has the greatest value followed by 60:40. The next process is Multi Objective Linear Programming which is a method for solving optimization problems with multiple factors influencing decision results with linear constraints and direct direction functions in the form of linear ones. The MOLP results show that the weight of the Geopolymer in MOLP mortar with silica fume with the best percentage is 0.99.

6.3. Waste Reduction Strategies

Within the current building industry, progress has been made regarding the identification of materials and designs that can lead to a reduction of the environmental impact associated with buildings, both in terms of the resources used for their construction as well as for the energy required for the operational and maintenance phases. The aim of the study is to explore the methodology to take into account environmental aspects in the choice of materials for the building process and to evaluate the environmental impact of different disposal strategies, adopting Life Cycle Assessment (LCA) methodologies. The focus on building materials is crucial because this is where the greatest improvements can be made to reduce the environmental impact of the buildings themselves. Life Cycle Assessment (LCA) is suggested as a tool to be used for estimating the operating and servicing energy costs over the life of a building and to compare the environmental impact of disposal strategies [7]. To take into account the building sector’s environmental impact in the construction phase; when a building is demolished, its materials can be recycled, with positive environmental effects. The possibility to assess the concrete sector's environmental impact within the decision-making process to define industrial policies and the implementation of preventive measures; the knowledge of the life cycle of a product (concrete in the form of precast elements). The methodological approach applied consists of two parts. The first one is the assessment of the environmental impact of the preparation of geomaterials, which are the output products of the selected industrial process schemes. This part is carried out according to the Environmental Impact Assessment (EIA) methodology. The second part of the work consists of a case study concerning an example of the application of the considered precast concrete components in the construction of a real building. The end of life (EOL) options for the entire building are considered. This part of the work, considering the entire life cycle of the building, is carried out according to the Life-Cycle Assessment (LCA) methodology.

7. Industrial Applications of Geopolymer Concrete

Recently, there has been a considerable interest in developing sustainable and environmentally friendly construction materials in order to minimize the environmental impact of using cement-based concrete. Geopolymer concrete is a representative example that can potentially reduce the amount of CO2 emissions by transforming waste materials into value-added products and avoiding the calcination of cement powder. The long-term engineering properties of geopolymer concrete are still in controversy since the silicate polymerization of aluminosilicates in geopolymer concrete continues more than 28 days and depends on various factors. In this study, the engineering properties of geopolymer concrete are compared with those of cement concrete, focusing on the compressive strength, shrinkage, and weight loss of geopolymer concrete up to 90 d after casting. Moreover, a comparative study is presented based on the comprehensive analysis of life-cycle assessment and environmental impact assessment. There are a lot of studies dealing with geopolymer concrete in the fresh state, comparing its properties with those of conventional cement concrete. However, information is lacking about the long-term engineering properties of hardened geopolymer concrete, and more effort needs to be made to better understand the long-term properties by verifying the durability of geopolymer concrete. This paper will provide new insights into the long-term strength behavior of hardened geopolymer concrete by comparing the compressive strength test results for geopolymer and cement concrete over 90 days. In addition, the shrinkage and mass loss of geopolymer concrete set and cured in ambient conditions are measured up to 90 days to identify its long-term stability. Similarly, the shrinkage of cement concrete is closely related to the formation of a crack, which leads to the penetration of external chemicals into the matrix. The difference in shrinkage behavior between geopolymer and cement concrete observed are discussed from the results of the autogenous and drying shrinkage tests. Many mass-construction researches present the shrinkage results of fly-ash-based geopolymer concrete which is cured in a hot-bath. However, the mass loss of geopolymer concrete is hardly found in the literature. Information about the mass loss mechanism of geopolymer concrete is very limited as well. In light of the abundance of information about the shrinkage and mass loss of cement concrete, understanding the shrinkage and mass loss behavior is crucial to predict and estimate the long-term structural properties and safety of geopolymer concrete.

7.1. Construction Industry

The huge demand for building materials with the surging demand for urban construction has brought considerable pressure on the environment. With the depletion of natural resources and the deterioration of the ecological environment, countries around the world face severe challenges in sustainable development of the environment and resources. Green construction centered on building a more sustainable environment has become a central concern for scholars and engineers all over the world. It is essential for decision-makers to evaluate the environmental impacts of the construction industry and building materials so that they can develop sustainable strategies and effective actions. There are numerous methods and techniques that can evaluate the environmental impacts caused by activities, events, and products. Among them, Life-Cycle Assessment (LCA) and Environmental Impact Assessment (EIA) are the most widely used and accepted.

In order to effectively reduce the negative impact of the construction industry on global warming, countries around the world are also actively responding to reduce energy consumption and emissions. China has put forward the goal of 'reaching the carbon peak by 2030 and becoming carbon neutral by 2060'. Increasingly, building materials that can effectively reduce the negative impact on the environment are in high demand. Historically, well-cemented concrete has been the material of choice in the construction industry because of its simplicity to produce, lesser cost, durability, and good mechanical strength. However, one of the most imperative needs now is the construction of sustainable and environmental-friendly infrastructure, which includes the use of low-energy and low-CO2 footprint materials. Silicate cement is one of the most used building materials in modern construction. However, the industrial production of cement has numerous negative environmental impacts. The energy consumed in its production reaches 10% of the total global energy consumption, principally in the grinding and heating process. Additionally, during the different manufacturing stages of silicate cement, emission of greenhouse gases is produced. The raw material itself is calcined at a high temperature (range up to 1450 °C) for the manufacturing of Portland cement, resulting in the emission of carbon dioxide in a high volume [2]. Geopolymer concrete (GPC) is a new type of material that is fast gaining popularity because of its ability to develop durable products using less energy-intensive and emissions-intensive ingredients. Despite the aforementioned advantages of GPC over OPC, usually available literature only concerns issues regarding strength and setting time. In terms of environmental assessment, there are only a limited number of related studies on GPC.

7.2. Infrastructure Projects

7.2. Infrastructure Projects (Sample Text; A range of Geopolymer Concrete Premixed Blends suitable for precast infrastructure applications such as pipes, kerbs, culverts, bridge beams, and barriers are being developed. These are designed to be FLYASH, SLAG or NATURAL POZZ infilled with coarse substrate aggregate and rock like course sand.) Similar to infrastructure components, it seems clear from analysis that Geopolymer Concrete offers a more environment friendly choice in the manufacture of infrastructure projects. To-date a number of these studies have been accepted for publication. Geopolymer Concrete should assist in minimising urban heat island impacts and should incorporate local natural minerals as appropriate and possible. Non destructive methods should be used to investigate any micro-environmental effects of Geopolymer Concrete public amenities such as seating, kerbs, barbeques etc.

In a recent examination negative hydrogen ions were found escaping from a variety of building materials into surrounding air shedding a negative influence. A Geopolymer Pre-cast Concrete has been developed to incorporate negative ions which are released in water. This represents a significant future commercial opportunity. The implications of rapid precaster implementation of Geopolymer Concrete pre-mixed blends are considered in the context of emerging competitive disadvantage between Geopolymer Concrete infrastructure construction techniques and traditional civil construction methods. Initially this will manifest as loss of marketshare by the civil construction industry, likely to be opposed and fought by industry actors with resources and political links, conspiring to limit market access and freedom of innovation options. Ultimately this conflict of interests subsides. However Geopolymer Concrete buildings and installations will be at a competitive disadvantage until the precaster industry has migrated to using the technology.

The time taken for this implementation to occur will be major factor as Geopolymer Concrete pre-caster products must inherently be less competitive in price and options with pre-existent traditional building technologies. This reality will define a commercial window of opportunity for remuneration from research and development of multiple Geopolymer Concrete technology innovations. Such remuneration may take the form of royalties, product licenses, technology transfer, or other negotiated commercial agreements. Early investment of resources should reflect this understanding. Adapt pressure entry door frame applications nearing conclusion to a new subject, and develop a suitable form description and conceptual diagram in readiness for the commencement of a new submission post-assessment format.

7.3. Precast Concrete Products

Expansion in infrastructural growth and construction industry results in more energy resources and depletes the natural minerals. Using an alternative construction material with less usage of ordinary Portland cement is a need of the present scenarios. Geopolymer concrete is derived by binding materials that are combination of fly ash, ground granulated blast furnace slag and aluminosilicate in presence of activators. There is a noticeable growth rate in the production of precast concretes. Precast products are casted in factories where they are monitored with quality and can be erected on site by reducing the time consumption, reuse and recyclable of products. This paper mainly discusses the life-cycle assessment and environmental impact assessment of geopolymer concrete and normal concrete casting by precast casting method. A suitable mixing ratio is derived from the compression test of the geopolymer concrete specimen. The pouring of concrete in the forms of pole is done by 110 numbers where the life-cycle assessment is performed on two types of casting concrete specimens. Ozone depletion potential is found to be considerable higher in the geopolymer concrete cervical specimen due to the 5.5 kg of wire used whereas other environmental impacts were found higher in normal concrete erection specimen. There is no significant different in the normalized midpoint impact category results in LCA process associated with the transportation. The geopolymer concrete transportation and casting specimens are found to perform better in the normalized single score category.

8. Challenges in Implementing LCA and EIA

Until recently, the life-cycle considered in LCA studies was related to the production process of a product or technology. Nevertheless, there is today a growing need to increase the spatial and temporal boundaries of LCA analyses. It is this extension that encompasses EIA within BCAs to deal with the identification of the main distribution of environmental impacts of a product, material, design, process, material or structure. In addition, the life-cycle assessment within the framework of BCAs considers the environmental impact associated both with the preferred option and with the most likely or business-as-usual alternatives.

The practice of LCA application as one of the major tools to perform EIA is on-going. It is a very powerful and multidisciplinary tool to analyze and assess the environmental implications of products and systems. A number of European Directives has consequently been focused upon studying such aspects and several research contracts have been concluded. To try to assist the increased interest in it, the European Commission is revising its guidelines concerning the practice of LCA. Methodological and interpretative approaches that had been hotly debated about a decade ago have made their way into the standards. Now that the review is nearing completion, it permits self-reflection on the marine environment evaluation to which it might have possibly contributed. The methodological elements in the revised guidelines are capable of providing an approach that should improve the quality of such assessments. Five years on, these opportunities are tentatively explored here, the current status and the eventual perspectives. Better application of LCA, both in a broader and more thorough way, could be of great assistance to environmental policy-making in general and to the setting-on of the issues of sustainable exploitation of energy and the sea.

8.1. Data Availability and Quality

Many studies have increased attention on the development of geopolymer concrete (GPC) due to the climate change crisis's worsening situation, the exacerbation of the greenhouse effect, and the frequently occurring extreme climate events. However, limited research has been conducted on the life-cycle environmental performance of GPC, and comprehensive comparative environmental assessments between GPC and ordinary Portland cement (OPC) have been scant. With the resources' increasingly substantial appropriation for infrastructures, the opportunity was taken to carry out a detailed review of LCA and EIA research for eco-efficient concrete alternatives [2]. As uncertainties on the environmental influence of geopolymer technology in the literature review exist, the first objective was to determine the environmental influence (by covering a broad range of impact categories and by taking the entire life-cycle into account) of geopolymer concrete overlaying existing FA. The second objective was to compare FA geopolymer concrete and OPC concrete with the same quick-setting process in terms of environmental and financial efficiencies by applying LCA and EIA methods. For both objectives, the local FA geopolymer concrete overlaying an existing roadway in Northwest Europe was examined. The original contribution of the study was in combining a life-cycle approach with a construction-phase examination. Additionally, a prototype value for the modelling of FA geopolymer concrete was presented, which can be of great assistance in standardization efforts. The quality of the data for GPC in the databases available, environmental influence related to production processes, construction phases, and end-of-life, environmental efficiency in various impact categories by a life-cycle perspective, engineering performance of FA GPC overlaying existing FA including GHG emissions during a rapid setting process compared to FA OPC, and a combined with cost-benefit analysis, including uncertainty and sensitivity analyses were the Wider research questions tackled.

8.2. Regulatory Frameworks

In limiting the environmental impact of new products, it is necessary to extend the time frame of environmental assessments to cover the entire life cycle of a product. Indeed, there are few global warming potential (GWP) values included in hazard assessment research, which do not include construction processes, and there is little research on comparative analysis with ordinary concrete. It is worth mentioning that 44.95% of the GWP value of the superstructure comes from the construction stage and then increases the utilization rate of tower cranes and construction machinery during the construction stage, which can effectively reduce energy consumption since most of the energy consumed during the construction stage is fuel [2]. There are three main points to consider when carrying out Life-Cycle Assessment (LCA) studies of cluster-based geopolymer concrete using the 20 mm defect-free basalt. As the size of the defect-free basalt aggregate increases, the specific energy consumption in the production of basalt aggregate decreases, and the values of other types of energy consumption remain almost the same. Second, in comparison to the previously tested basalt and other aggregates, the average mechanical performance of the geopolymer concrete samples is higher. As cellulose addition increases, the bulk density of geopolymer concrete decreases while the heat of hydration increases. There is a direct quadratic relationship between the compressive strength of geopolymer concrete and heat of hydration.

8.3. Stakeholder Engagement

Partnership with public bodies, non-profit associations, and artisan trade associations will be progressively increasing over time expressly dealing with the intermediation by the Consortium for the sustainable development of Viareggio. More generally, two types of the output are expected to affect the Cluster performance: the effectiveness based on local impact and networking appliances. Engagement in the process of local impact involves the capacity of the Cluster to obtain consensus from the local stakeholders. It implies a permanent, unpredictable, and not accurately predictable process of relationships with the territorial players.

9. Future Directions in Research

As the approach to the “one size fits all” paradigm has proven it is outdated, future work in this catalog will not only concern GDPs, as a class of materials, but will seek to address what is specific to each potential Geopolymer precursor/material. In keeping with the results of the present investigation, a first step in that direction is the life-cycle assessment of a selection of the most common precursors and materials, such as fly ash, blast-furnace slag, red mud or metakaolin.

This goal can be achieved by developing early stage research defining the research context and identifying the implications. The need for and benefits of investigating the economic dimensions of GDPs throughout their life-cycle are stressed and conceptual gaps in understanding the materials already exploited in cement-based concretes addressed. A broad empirical range is used to illustrate the current economic status of GDPs and changes in their economic effects during manufacture and processing identified. Recommendations for future research in this area are made, with a focus on cross-cutting implications of composition and material properties, and an agenda to encourage greater multi-disciplinary investigation is outlined [8].

Thus Geopolymer is formed which may be considered as a major constituent for eliminating the use of OPC which is more environmentally friendly, cost effective and useful for enhancing the strength. There is a strong need for an alternative material for the construction industry which can replace cement. Geopolymer concrete is a sustainable, cost-effective and eco-friendly green construction material. This review paper critically explores the previous investigational work carried out worldwide on GPCs. It can be stated that geopolymers can be a perfect alternative to conventional building materials. Concerning the highly alkaline conditions required for geopolymerisation, unpurified geopolymer products display apparent viscosities comparable to those of honey, highlighting the importance of geopolymer binders in Geopolymer concretes.

9.1. Innovations in Geopolymer Technology

The need to develop more environmentally friendly building materials that take into account sustainability issues and the consumption of raw materials has significantly increased in recent years. The study of potential innovations appears of primary importance, which can lead to an improvement in the performance of the materials produced. The interest in the development of the geopolymer technology is placed in this framework. This technology is a particular type of green cement realized by polymeric reaction and characterized by a low energy demand and a strong reduction of greenhouse gases. The geopolymer concrete is produced by means of the chemical reaction between an aluminosilicate material and a highly alkaline activator solution. The raw materials are cheaper than those required for the ordinary Portland Cement. Furthermore, this material does not require the limestone decarbonation that represents one of the utmost polluting processes of the cement production. A geopolymerization makes it possible to reduce industrial waste. The properties of the produced concrete are compared with those of the conventional material. The workability is determined with different methodologies, which are the slump test, the flow table test, and the V-box test. Moreover, a full study of the microstructures of the material produced is performed. Finally, the development of the compressive strength is studied and it is examined if a geopolymeric concrete can be produced by the used waste ash and the used procedure [9]. Since the pioneering contributions of Davidovits, a researcher of French origin, the geopolymer technology gets rid of the simple curiosities of enthusiasts and begins to involve more and more industrial and academic figures. The noise has pushed many research centers and universities to work on geopolymer for different purposes and studies. Beams and reinforced columns made of geopolymeric concrete are manufactured and tested. A post-tensioned reinforcement is used in the beams. The test variables are the longitudinal tensile reinforcement ratio and the compressive strength of the concrete. The beams are cured at different temperatures (including ambient temperature) and a comparison of the mechanical properties between the cold-cured and heat-cured beams are presented. Some beams are not post-tensioned and are simply cured at high temperature. The mechanical behaviors of regular and post-tensioned beams, cold cured and heat cured are compared. In the columns the test variables are the longitudinal reinforcement ratio, the load eccentricity and the compressive strength of the concrete. The mechanical properties (strength and ductility) of the reinforced geopolymer concrete columns under short-term eccentric compressive loads are studied. Calculate the capacity and ductility of the beams and columns by using one or more of the existing methods employed for predicting the strength and behavior of reinforced concrete, and perform a comparative analysis. Also, calculate the geopolymer columns and beams according to most recent design standards and guidelines and prepare a brief note describing the available design equations/methods. Validate the calculated results by comparing them with the test results.

9.2. Advancements in Assessment Methodologies

According to the data provided by US EPA and USCPSC, around 400 bridges collapse annually in the US due to heavy load, vehicle accident and old age. In 2007, the bridge infrastructure report of Federal Highway Administration showed that 31.3% of all bridges in the US were either structurally deficient or functionally obsolete in 2006. For instance, the figure for bridges satisfying this condition in Idaho is 68% [4]. In the US, the average age for bridges is 42 years, while 42% of the bridges are older than 50 years. At least 25% of the bridges have already reached their historical service lifetime. A need to perform extensive repair has been predicted in the future and the 2007 estimation of cost is 73.1 billion dollars.

Life-Cycle Assessment (LCA) and Environmental Impact Assessment (EIA) are tools that can be used to access the environmental impact of a product, process or system. The former can be used to identify environmental impact hotspots throughout the life of a particular product, process or system, while the latter can provide an overall view. These tools have been standardized by ISO and widely applied in different industries. Such methodology has been applied to green concrete with highest compressive strength in the test data, and a clear view has been provided to bridge engineers, that they can modify the concrete mix design or select better combination alternatives. Similar methodologies have been reported on thermal energy storage materials. Here, the collection of databases, normalization, weighting, and impacting assessment were reviewed. Although one industry case study on concrete was shown as an application example, there were still several points needed to be discussed [2].

The amount of energy consumed and pollution produced in each life stage can be controlled at the design stage in other industry, like electronics, automobiles, etc. However, for civil engineering industry, LB is also needed to test the life cycle in order to improve the waste of energy and emission of pollution in the construction, operation, maintenance and end-of-life stages. The ALCC step in ISO is divided into four stages, which are acquisition or supply, manufacturing, operations, and end-of-life. Although the LCA of GPC was rarely seen in the last two decades, the GPC is attracted to be studied recently. Among all the published papers, most of GPC was made of fly ash, and the mix proportion of it was activated by alkaline solution and other silicates. Only few articles report LCA of GPC or blended GPC as a substitute material for catalysts or plaster in the context of additive coating.

10. Conclusion

Life-cycle assessment studies can be undertaken to determine the long-term benefits of having geopolymer concrete as part of the infrastructure network. It has also been shown that the energy used in production of geopolymer concrete is less than that required for conventional Portland cement. In addition, the environmental impacts of constructing residential buildings using geopolymer concrete systems were less severe in the emission of greenhouse gases than for concrete houses. Furthermore, the production of fly ash-based geopolymer concrete systems emits about 80% less CO2 than for ordinary Portland cement. Geopolymer concrete and composites have gained wider acceptance for use in structural members recently.

Few experimental research findings of the members in simple geometric shapes incorporated with geopolymer concrete material subjected to flexural and axial compression loadings are currently available. Manufacture and testing of twelve simply supported reinforced geopolymer concrete rectangular beams under monotonically increasing load with both the longitudinal tensile reinforcement ratio and the concrete compressive strength as the test variables. Manufacture and testing of twelve reinforced geopolymer concrete square columns, including three short-term eccentric loading columns, with both the longitudinal reinforcement ratio and the load eccentricity ratio, and the concrete compressive strength as the test variables. Calculation procedures to predict the strength and the deflection of geopolymer concrete test beams and columns, using the design code commonly used for conventional Portland cement concrete members. The correlation of the test and calculated results, crucial for the practical design of geopolymer concrete composite members, has been studied. Lastly, the potential using heat-cured low-calcium fly ash-based geopolymer concrete in reinforced concrete beams and columns is demonstrated with the presentation of the member test results.

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