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Development of Geopolymer Concrete for the Protection of Environment: A Greener Alternative to Cement

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Abstract

There has been rapid usage of concrete for infrastructure development in the present scenario all around the world. Consumption of cement in making concrete has proven to be posing a potential threat to our environment in terms of massive carbon footprints into the environment causing global warming. Sustainable development in the construction industry has been a major research area in the present decade, and geopolymer concrete is one such development towards sustainability. Geopolymer concrete is concrete without cement but better than OPC based concrete in all aspects. According to various research, limestone reserves are on the verge of extinction, and climate change has been an important environmental issue worldwide due to carbon emissions. This review paper presents the environmental issues by empirical data/surveys related to emissions of CO2 gases specific to the cement industry conducted by eminent scientists/researchers and several environmental research bodies and online non-government organizations. The literature in this paper focuses on experiments conducted worldwide in promoting geopolymer concrete as a green-building material stressing the importance of using eco-friendly construction material for sustainable development.

Keywords - *Geopolymer Concrete, carbon footprint, global warming, green building material, eco-friendly construction, sustainable development*

I. INTRODUCTION

Global warming has become a colossal threat since the Industrialization and urbanization era. Cement industries gained popularity as concrete is the second most utilized material just after water. The trend of production of cement has seen a geometric progression. From consuming approximately 1100 million Metric Tonnes in 1990 to 3270 million Metric Tonnes in 2010, there has been a steep rise in cement consumption [1]. This number is expected To grow further, up to 4830 million Metric Tonnes in 2030 [1]. The production of cement is both an energy and resource-intensive process. The production of 1 tonne of ordinary Portland cement nearly produces an equivalent amount of CO2 [2,23] and consumes a huge amount of limestone, a non-renewable natural resource. Moreover, the concrete making process uses an enormous amount of water. The energy associated with the production of cement is nearly 4 GJ per Metric Ton [18]. Rapid industrialization has other side effects; industrial waste disposal is a severe problem that poses a considerable threat to the environment. Industrial wastes like Fly Ash, Slags, Rice Husk Ash, Silica fumes, Tailings, etc., pose a huge threat when released into the environment. Steps have been taken to utilize these materials; however, complete utilization of these wastes has still not been possible. Fly Ash is mainly generated by the power plants in the combustion of coal in a boiler to form steam. Slag is a waste produced by the steel industry and mainly consists of metal oxides, Calcium, and silicon dioxides. Rice husk ash is an amorphous silica-rich by-product of rice processing.

Similarly, silica fumes have very fine particles, with the average particle size being 1μm [21]. It is produced as a by-product of ferrosilicon industries. Tailings are the waste of the mining industry, the leftover materials after the extraction of valuable minerals. These materials accumulate in the environment, and over time can pose a huge threat to flora and fauna. Some of these materials are used in construction industries, but the use is still insufficient to consume all of the material generated.

There has been a significant rise in CO2 emissions, from 3.099 Metric tons per capita in 1960 to 4.970 Metric tons per capita in 2014, with a record high of 4.996 Metric Tons in 2012 [3] (up till 2014). Moreover, 9.9 giga tones of CO2 was emitted into the air in 2017. CO2 constitutes about 76% of the total greenhouse gases [4]. However, there are major sources of CO2 formation; one of the biggest contributors to these emissions is the cement industry, which nearly accounts for 7% of the total CO2 emissions in the world [5, 20]. Cement formation is a very energy

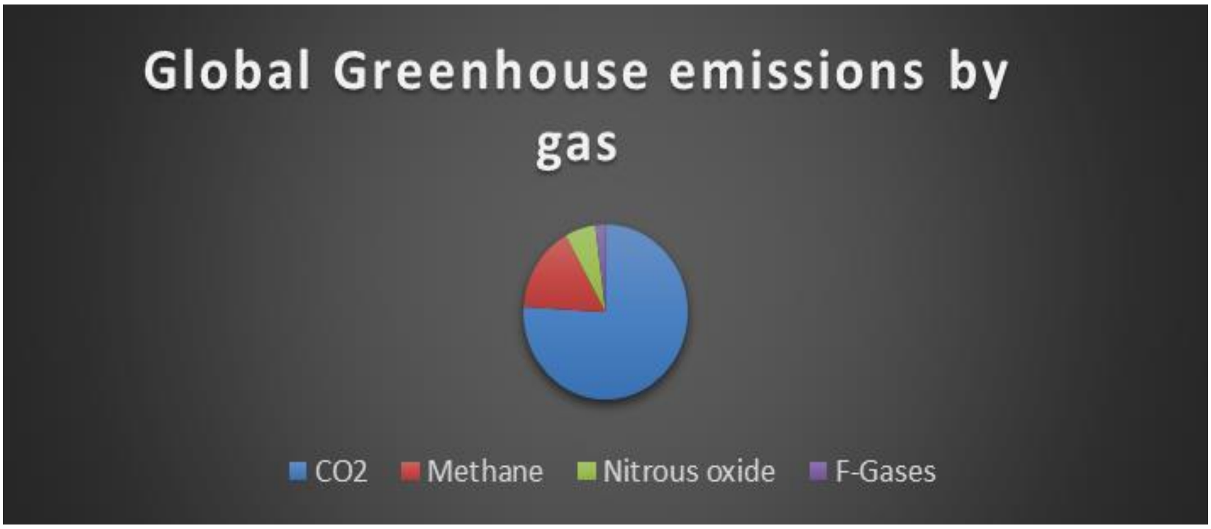

CHART. 1. Global Greenhouse emissions by gas (© IPCC 2014)

Intensive process, during the sintering and grounding process, a lot of energy is consumed, and this energy is primarily supplied through fossil fuels.

II. CONCERNS AND ENVIRONMENTAL DAMAGES CAUSED BY CO2 EMISSIONS

CO2 emission rates have seen almost a steady growth over the years, with a steep rise seen from 1961 to 1973 and 2002 to 2012 [4]. CO2 is one of the major greenhouse gases and has a major impact on the environment, and these changes can be reversible or irreversible. The effects of CO2 have humongous climatic impacts, including permafrost, arctic ice retreat, loss of glaciers and snowpack, increase in heavy rainfall and flooding, increased intensity of hurricanes. Furthermore, there has

Been a gradual increase in global temperature due to the increment in greenhouse gases.

There are numerous greenhouse gases, but the highest percentage of these gases is CO2. Carbon dioxide emissions occur due to various activities. The cement industry contributes to nearly about 7% of these emissions [5, 20]. Most of this energy consumed
is in the process of sintering and grounding the cement. The industry has seen a gradual growth in the years.

III. GEOPOLYMER CONCRETE: A SUSTAINABLE MATERIAL

Geopolymer concrete is considered as the third generation concrete after cement and lime binder

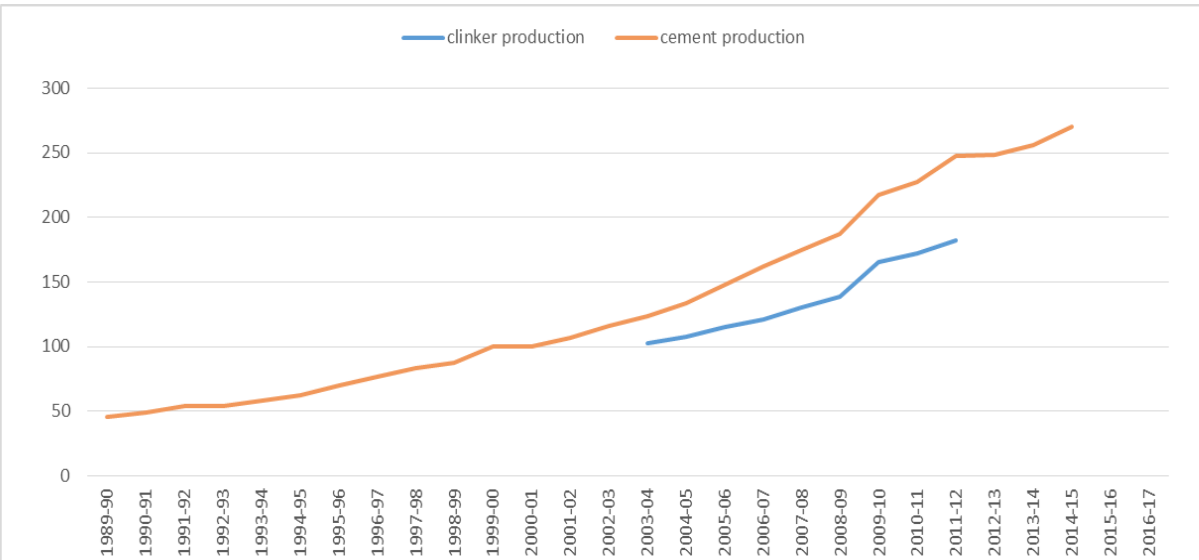

Fig. 1. Cement and Clinker production of India from 1986-2017 (Andrew & Robbie, 2018)

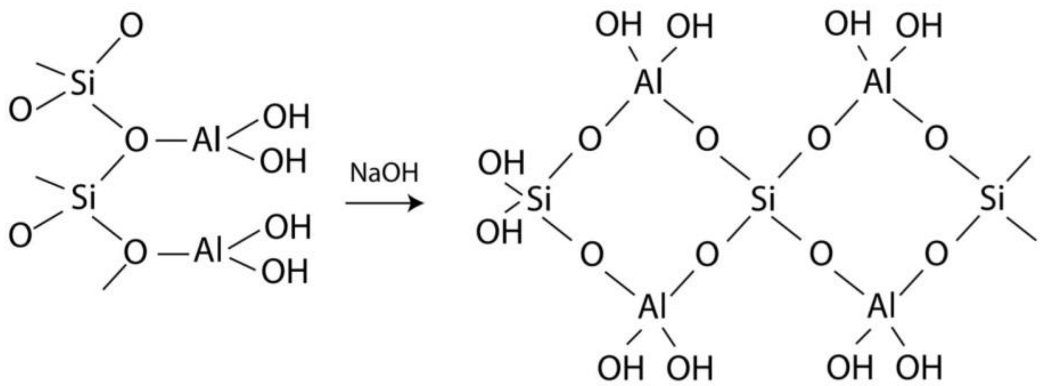

Fig. 2. Polycondensation of kaolinite Si2O5, $Al_2(OH)_4$ in alkali medium (Joseph Davidovits).

Based on concretes. French chemist Joseph Davidovits coined the term Geopolymer in 1978, and he developed a new kind of polymeric binder by using aluminosilicate kaolinite in the presence of alkaline liquids 100-150o C [7]. He observed that the above process leads to polycondensation. In general

Geopolymer concrete is a block of concrete without cement and a negligible amount of water. Unlike conventional cement concrete, the hydration process doesn’t occur

in the geopolymer concrete, hence neither water is required for reaction nor the curing process. The polymerization process is responsible for the binder synthesis, similar to zeolites, but the precursors can be geological or industrial origin [7]. Fly ash, Ground Granulated Blast Furnace Slag (GGBS), Silica Fume, Rice Husk Ash (RHA), Sludge, etc., is a hazardous waste of various industries causing serious damage to the environment and the community around them. To utilize these materials for geopolymer concrete production as precursors, various researchers have conducted extensive research worldwide. As a result, the Geopolymer has shown its tremendous potential to be used in construction industries in place of conventional concrete with added benefits of environmental sustainability. Geopolymer concrete production is very less energy and resource-intensive process; it utilizes the solid waste generated by various industries and helps solve the dumping issues regarding its disposal.

Iv. POTENTIAL INDUSTRIAL WASTES FOR GEOPOLYMER CONCRETE

A. Fly-ash

Fly ash is the waste generated by the thermal power plants during the process of energy production. Since the energy demand is increasing tremendously with rapid industrialization and urbanization, the Production of this waste has increased manifolds. In India, fly ash's annual production in 2017, and 2018 was 169.25 & 169.44 million tons, respectively [8]. Fly Ash is rich in silicon, aluminum, and Calcium Oxide; furthermore, fly ash is classified into Class-F and Class-C about ASTM standard C618 - 17a. This classification is done based on the calcium oxide content in the fly ash. The Class-F Fly Ash is produced from the high ranking coal, and the Class-C Fly Ash is produced from the low ranking coal, due to which there a higher content of Calcium Oxide present in Class-F fly ash. Khairul Nizar et al. investigated fly ash properties generated by two different thermal power plants in Malaysia [9]. The chemical and microstructural properties of these fly ashes were studied by XRF and SEM analysis. The results are shown below in table 1.

Chemicals Oxides	Fly Ash(Sultan Azlan Shah Power Station, Manjung Perrak)	Fly Ash(Sultan Abdul Aziz Shah Power Station, Kapar, Selangor)
SiO_2	26.4%	52.11%
Al_2O_3	9.25%	23.59%
Fe_2O_3	30.13%	7.39%
TiO_2	3.07%	0.88%
CaO	21.6%	2.61%
Na_2O	---	0.78%
K_2O	2.58%	0.42%
P_2O_5	0.67%	0.80%
SO_3	1.3%	1.31%
MnO	0.27	0.49%

Table-1. XRF analysis of fly ash from two power plants in Malaysia (K.Nizar et al. 2014)

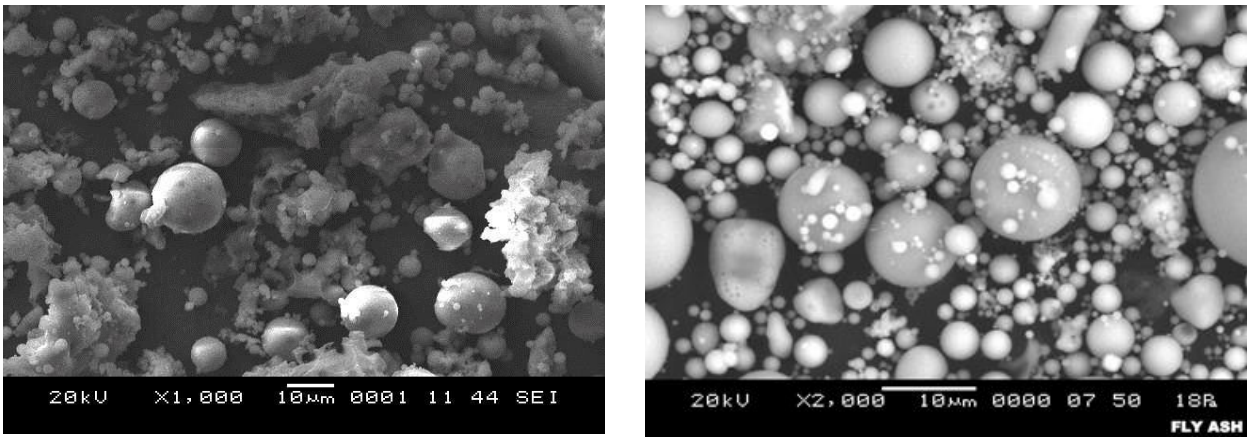

Fig. 3. SEM micrograph of the fly ash from Sultan Azlan Shah power station and Sultan Abdul Aziz Power Station respectively (K.Nizar et al. 2014).

B. Ground Granulated Blast Furnace Slag (GGBS)

When a mixture of iron ore, limestone, and coke is introduced in a blast furnace at about 1500 degrees Celsius the iron ore gets reduced iron, and the slag starts floating on top. GGBS chemically constitutes calcium oxide, silica, alumina, magnesia, and some amount of ferric oxide. It is a pozzolanic material and is used for partial replacement of cement, and the cement is known as Portland slag cement (PSC) or Portland Blast Furnace Cement (PBFC) furthermore. Due to the presence of high silica and alumina content present in GGBS, it has a tremendous potential to be used as source material for geopolymer concrete. The physical and chemical properties of GGBS are mentioned below in table-2-3, respectively.

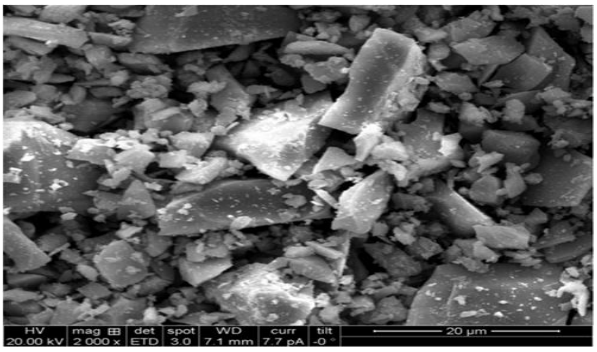

Fig. 4. SEM image of Ground Granulated Blast Furnace Slag (V Nagendr et al. 2018)

Physical Properties	
Colour	Off White
Specific Gravity	2.9
Bulk Density	1200 Kg/m^3
Fineness	350 m^2/Kg

Table-2. Physical Properties of GGBS (D. Suresh and K. Nagaraju)

Chemical Composition	Percentage by Mass
CaO	40%
SiO_2	35%
Al_2O_3	12%
Fe_2O_3	0.2%
MgO	10%

Table-3. Chemical Properties of GGBS (D. Suresh and K. Nagaraju)

C. Rice husk ash (RHA)

Rice being one of the staple food products consumed worldwide, is produced in humongous quantities. Out of the 715 million tons of paddy produced globally, we get around 20-30 million tons of Rice husk ash [18]. The rice husk is charred in biomass energy production, and the residue left behind is rich in carbon, silicon, and aluminum. This solid black residue is known as Black Rice Husk Ash. When kept in contact with air, this Black Rice Husk Ash oxidizes to form White Rice Husk Ash. The white Rice husk Ash is very rich in silica, and this high silica content makes it an ideal fit for partially substituting it in place of the source material in geopolymer concrete as a strength enhancer. Geopolymer concrete requires a high amount of silica for the synthesis of polymers.

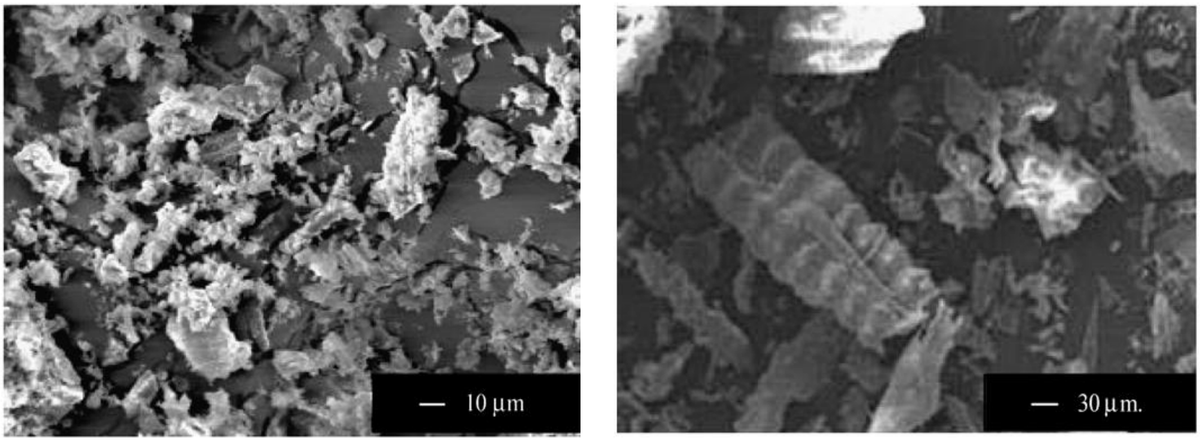

Fig. 5. SEM images of ground and unground Rice Husk Ash (P. Chindaprasirt et al. 2008)

V. GEOPOLYMER CONCRETE VS. OPC CONCRETE

Extensive studies have been carried out on both Geopolymer and OPC concrete to study their properties, durability, and behavior under various conditions. A lot of focus has been given to the sustainability aspect of concrete. Strength enhancement materials, durability studies, and pozzolanic waste material for partial replacement have been the primary concrete research fields. OPC based concrete has a lot of cons over geopolymer concrete. Geopolymer concrete poses a sustainable alternative due to a lot of factors. Geopolymer concrete has a lesser carbon footprint, consumes very little to no water, and does not consume limestone's natural resources. Furthermore, it utilizes industrial aluminosilicate wastes and is resistant to carbonation, sulfur, and chlorine attack. The polysilicate bond formation is faster than hydration-based C-S-H gel formation in normal concrete when cured at elevated temperature.

In conclusion, Geopolymer concrete can be the next generation of concrete with lesser emissions, higher durability, and faster production.

A. Workability

The rheological properties of geopolymer concrete are quite different from conventional concrete, but they still display a similar trend in the flowability characteristics. Various factors affect geopolymer concrete's workability, such as alkaline liquid ratio(R), the concentration of sodium hydroxide, water content, the morphology of source materials, etc., [16,18]. P. Nath and P. K. Sarker conducted various tests by partially replacing fly ash with GGBS in geopolymer concrete and found a reduction of workability and setting time with the increment of GGBS percentage [15]. P. Chindaprasirt et al. tested the effect of various parameters like NaOH concentration, the alkaline liquid ratio, etc. and stated that by the increment of these parameters, the workability reduces.

or

Fig. 6. Conventional concrete and Geopolymer concrete specimens (G71-28 & G54-44) after sulfate attack (X. J. Song et al. 2005)

The strength property of geopolymer concrete has been experimentally proven to be higher than normal OPC concrete. Partha Sarathi Deb et al. have experimented on the strength properties of GGBS blended fly ash geopolymer concrete and got the highest strength of 65 MPa at 180 days [12]. Furthermore, S. Kumaravel and K. Girija reported an average compressive strength of 66.67 MPa of geopolymer concrete with fly ash and GGBS [13]. D. Hardjito et al. investigated fly ash-based geopolymer concrete and observed strength of about 80 MPa with heat curing [14]

C. Durability

Geopolymer concrete has portrayed exceptional resistance to chemical attacks. X. J. Song et al. studied the durability aspects of fly ash-based geopolymer concrete in a high concentration sulfur environment. An OPC concrete sample was taken as a control to study the effect of sulfur attack after 56 days. The mass loss in OPC concrete was more than 41%. In contrast, the geopolymer concrete displayed a substantial resistance towards sulfate attacks showing a mass loss of less than 3%. [17] The visual effect of the attacks on the specimens is shown above in the figure-6.

M. Olivia, H. Nikraz tested the corrosion resistance of geopolymer concrete with reference to control concrete. They found the Geopolymer concrete to have a much higher resistance than the control concrete [19].

VI. CONCLUSIONS

Based on all the studies and comparisons in the paper, we can infer that CO2 footprints have been increasing in the atmosphere and have now reached threatening levels. The cement industry is a big contributor to these emissions; moreover, cement concrete consumes many natural resources and wastes a lot of water. Industries have been producing humongous quantities of aluminosilicate wastes, which they are unable to utilize. These products tend to degrade the environment; however, they can be used for partial replacement of cement in concrete or the generation of geopolymer concrete. Geopolymer concrete is a greener alternative to OPC based concrete and holds a lot of potential for the future as it is not very resource-intensive and is a greener alternative to the current generation of concrete. While on the one hand, OPC concrete consumes many non-renewable natural resources, has a huge carbon footprint, and is the cause of wastage of a lot of potable water, making it a threat to the environment. On the contrary, Geopolymer solves all of these problems and uses industrial as its source material. More research is required in geopolymer concrete, its contents, durability, and other viability aspects of implementing it on a large scale.

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