The Use of Geopolymer Concrete as a Sustainable Development in Construction Industries and Adaptation in Construction Management

[1]Mohammed Asif, [2]Khaja Fareeduddin
[1]Department -Civil Engineering, Lords Institute of Engineering and Technology, Hyderabad 500091, Telangana
[2]Head of the Department -Civil Engineering, Lords Institute of Engineering and Technology, Hyderabad 500091, Telangana

Abstract- Concrete, which is made up of cement, aggregates, water, and additives, is the world's most used construction material due to its versatility, durability, and dependability. Concrete is the second most consumed material after water, necessitating enormous amounts of Portland cement. The production of ordinary Portland cement (OPC) causes havoc to the environment due to the emission of CO2 as well as mining, which also results in unrecoverable loss to nature. Hence, it is urgent to find an alternative material to the existing most expensive cement concrete. Geopolymer was the best alternative material.

Keywords- Geopolymer Concrete, Sustainable Development, Fly Ash, GGBS, Construction Management, CO_2 Reduction, Durability, RCPT, Alkali Activation

INTRODUCTION

Geopolymer concrete is one of the building materials that is being more and more in the recent years. It is significantly more eco-friendly than concrete. This is a type of concrete that is made by replacing the OPC with suitable materials with similar properties. Waste products from the industries and factories like the fly ash, GGBS, kaolinite, feldspar, etc which contributes to a clean environment. This is so that the waste material does not need to be disposed of while it is being used, as it is really contained within the concrete. Carbon dioxide is not produced during the manufacturing of this concrete, nor is heat required. Concrete made using Portland cement needs both carbon dioxide and heat.

geopolymer concrete has come out as a promising alternative to traditional portl and cement concrete because of its potential environmental benefits and superior mechanical qualities. Unlike typical concrete, which uses Portland cement as a binder, geopolymer concrete uses aluminosilicate elements like fly ash or slag that have been activated with the help of alkaline solutions.

LITERATURE REVIEW

Previous studies highlight GPC as a sustainable alternative with excellent durability. Davidovits (1978) introduced the concept, while recent work by Pasupathy et al. (2021) and Singh et al. (2023) supports its superior resistance to chloride, sulfate, and acidic environments.

Ojha, A., & Aggarwal.P (2023):
They conducted a study to evaluates the durability of low calcium fly ash-based geopolymer concrete having a compressive strength of 30MPa. They used an alkaline activator solution of 14 molar concentration and a Na2Sio3/NaOH ratio of 2.5 to make geopolymer concrete with fly ash as the binder. They also compared the results obtained with the results of Portland cement concrete of the same grade. They tested the concrete moulds for water absorption, permeability, sorptivity, acid and sulphate resistance, and rapid chloride penetration tests to dtermine the durability.

Rudra Pratap Singh, Kumar Raja Vanapalli, Koteswaraarao Jadda, Bijayananda Mohanty (2023):
In this study they inspected the effects of fly ash (FA), ground granulated blast furnace slag (GGBS), and silica fume (SF) on the durability qualities of geopolymer concrete (GPC) against acid and sulfate attacks by replacing the 100% coarse aggregate with the recycled aggregate (RA).From which they concluded that the combined utilization of FA, GGBS, and SF has compensated for the adverse effects of using 100 % RA due to which the GPC has

shown excellent advancement in it's mechanical and durability properties .

Kirubajiny Pasupathy, Didar Singh Cheema, Jay Sanjayan (2021):
In this study they tested the long-term durability of fly ash-based geopolymer concrete after exposing it to a severe saline environment in which it was buried and completely soaked for a period of 10 years. From the test findings, they concluded that in comparison to OPC concrete, GPC concrete had a higher chloride penetration in the buried environment.

M. Kanta Rao, DCh. Naga Satish Kumar (2019):
In this study they conducted the rapid Chloride Permeability test to investigate what happens when cement is replaced with flyash material. They cast rcpt moulds with different combinations of L/B ratio and for all combinations, RCPT test was performed. From the rapid chloride permeability test values they found that concrete without flyash has the higher rcpt value than that of concrete with fly ash and it was observed that the Rapid Chloride Permeability Test readings were decreasing as the percentage of flyash increases.

Ajay Kumar Singh. (2016):
He performed tests such as compressive strength, split tensile strength and acid resistance by replacing flyash and ggbs over cement. Low calcium Class F flyash was used by him. From this assessment he concluded that the geopolymer concrete is light in colour and surface are more smooth than ordinary Portland cement. There is no mix-design code is available so it is needed to review on the results which had come out up to till date work done all over the world.

METHODOLOGY

The methodology of geopolymer concrete refers to the systematic approach to designing, preparing, and evaluating concrete made with geopolymer binders instead of traditional Portland cement. Here's a detailed breakdown of the methodology typically used in research or construction involving geopolymer concert

3.0 Research Steps:
3.1 Mixing and Casting:
Dry materials were mixed before adding the activator solution. The concrete mix was then poured into molds in three layers, each tamped for compaction.

3.2 Curing:
Specimens were cured either at room temperature or in an oven at 60°C, depending on the mix type.
3.3 Tests Conducted:
Compressive Strength: Cubes tested on 3, 7, 14, and 28 days.
Split Tensile and Flexural Strength: Cylindrical and beam specimens tested according to IS codes.
Rapid Chloride Permeability Test (RCPT): Following ASTM C1202, to assess resistance to chloride ion penetration.

DATA COLLECTION AND ANALYSIS

4.1 Primary Data Collection
To assess the potential of Ready-Mix Concrete (RMC) using GPC, data was gathered from literature, industry trials, and experimental research. Parameters included:

Material Composition: Fly ash, GGBS, alkaline ratio (NaOH to Na_2SiO_3), molarity

Mix Proportions: Binder content, aggregate ratio, water-to-binder ratio

Fresh Properties: Slump, setting time, workability

Hardened Properties: Strength at various ages, durability tests

Curing Regimes: Oven vs. ambient temperature

Environmental Metrics: CO_2 reduction, embodied energy, use of recycled materials

Example Data:
GPC with 12M NaOH, 2.5:1 activator ratio showed 28-day compressive strength of 45–50 MPa
Slump values varied from 65 to 95 mm
Up to 80% CO_2 reduction observed

Simulated Mix Comparison:
Mix GPC-1: Fly Ash, 12M NaOH, oven-cured at 60°C – 45 MPa, 90 mm slump, 80% CO_2 reduction
Mix GPC-2: GGBS-based, ambient cured – 58 MPa, 70 mm slump, 60% CO_2 reduction

Case Studies

Case Study 1: NTPC Kahalgaon Road Project (2024)

Location: Bihar

India Project Type: Road construction using GPC

Details: A 2.9 km stretch of road was constructed using GPC prepared from fly ash and GGBS without the use of OPC. The concrete was cured at ambient temperature and achieved M40 grade strength. The project demonstrated GPC's viability in large-scale infrastructure and promoted sustainable construction under NTPC's green initiative.

Key Observations:

Ambient curing achieved sufficient strength.

Demonstrated zero-cement construction.

Reduced carbon footprint substantially.

Fig.4.1

Case Study 2: Pune Urban Pothole Repair

Location: Pune, Maharashtra

Structure: Emergency road maintenance

Details: The municipal corporation of Pune used rapid-setting GPC mortar to repair potholes during monsoon season. The GPC mix set within 2 hours, significantly minimizing traffic disruption. The mortar was prepared with fly ash and sodium-based activators.

Key Observations:

IRC approved the methodology.

Effective under adverse weather conditions.

Enhanced service life of patches due to low permeability.

Fig.4.2

RESULTS AND DISCUSSION

6.1 Mechanical Performance
GPC shows high strength with proper curing and activator balance. Compressive strength exceeded 60 MPa in optimal mixes.
6.2 Durability
RCPT values indicate low permeability, suitable for marine and sulfate-prone environments.
6.3 Environmental Impact
Up to 90% CO_2 reduction observed, promoting circular economy via waste utilization.
6.4 Cost and Workability
Reduced curing energy in ambient conditions
Moderate slump values indicate manageable workability
Long-term lifecycle cost savings due to durability

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion
Geopolymer Concrete (GPC) is a viable and highly sustainable alternative to Ordinary Portland Cement (OPC) for modern construction. By utilizing industrial by-products such as fly ash and GGBS, GPC significantly reduces carbon emissions—up to 90% in some cases—while offering mechanical strength comparable to or greater than traditional concrete, especially when proper curing methods and activator ratios are applied.

7.2 Recommendations
Encourage pilot projects by public bodies
Standardize mix design guidelines
Invest in worker training for alkali safety
Promote GPC through environmental certification credits

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