International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 Issue: VII Month of publication: July 2024

DOI: https://doi.org/10.22214/ijraset.2024.63602

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue VII July 2024- Available at www.ijraset.com

Utilizes Industrial By-Products Fly Ash and Metakaolin Instead of Traditional Cement

Adil Ahmad[1], Dr. Manendra Pratap Verma[2], Dr. Vivek Soni[3]
[1]Ph.D Scholar, [2, 3]Professor, Faculty of Engineering and Technology, School of Civil Engineering Madhyanchal Professional University, Bhopal, M.P., India

Abstract: Fly ash and Metakaolin based geopolymer concrete offers a sustainable and effective solution to reduce the carbon footprint of the construction industry and manage industrial waste. This review highlights the significant progress made in the research and development of GPC over the past two decades. However, further research is needed to address the challenges and fully realize the potential of geopolymer technology. Future efforts should focus on standardization, long-term performance evaluation, and economic viability to facilitate the widespread adoption of GPC in the construction industry.
Keywords: Geopolymer concrete (GPC), Comprehensive foundation, Carbon footprint, thermal power plants

I. INTRODUCTION

The production of cement is a significant contributor to carbon dioxide (CO_2) emissions, which exacerbate the greenhouse effect. This environmental impact has spurred researchers to explore alternatives that reduce cement usage while maintaining concrete's structural integrity. One promising solution is the development of Geopolymer Concrete (GPC), which utilizes industrial by-products like fly ash instead of traditional cement. When combined with alkaline solutions, this mixture forms a strong, durable material known as geopolymer concrete.

A specific variant of this innovation is Self-Compacting Geopolymer Concrete (SCGC). Unlike conventional concrete, SCGC does not require mechanical compaction to settle into place due to its highly flowable nature. This attribute not only simplifies the construction process but also improves the quality of the finished structure by minimizing voids and enhancing uniformity.

The increasing environmental concerns associated with fly ash waste disposal and high cement consumption necessitate the effective promotion of geopolymer concrete (GPC). This paper outlines a specific mix design procedure aimed at developing GPC with a focus on achieving better compressive strength economically, using varying proportions of alkaline solutions to binder. The cement industry is a major contributor to global greenhouse gas emissions, with an estimated annual production of 1.35 billion tons of CO_2, accounting for approximately 7% of total anthropogenic emissions. Additionally, the growing industrialization has led to an increase in thermal power generation, producing large quantities of fly ash. The improper recycling of fly ash creates significant challenges for solid waste management.

A. Metakaolin

Metakaolin, indeed, is a dehydroxylated form of kaolinite, a clay mineral Metakaolin's versatility makes it valuable in both the ceramics and construction industries. Its ability to improve mechanical properties and durability, coupled with its environmental benefits as a partial cement replacement, underscores its importance in modern material science and sustainable building practices. Metakaolin is primarily composed of silica (SiO_2) and alumina (Al_2O_3). The dehydroxylation process removes the hydroxyl groups from kaolinite, resulting in a material with an amorphous (non-crystalline) structure. It is a fine, white powder with high reactivity due to its amorphous structure. The reactivity of metakaolin arises from its high surface area and the presence of alumina and silica in a highly reactive state.

Improved Mechanical Properties: In ceramics, metakaolin enhances the mechanical properties such as strength and durability. It can also reduce the firing temperature, making the production process more energy-efficient.

1) Glazing and Porcelain: Metakaolin is used in glazes and porcelain formulations to improve whiteness and translucency.
2) Pozzolanic Activity: Metakaolin is a pozzolan, meaning it reacts with calcium hydroxide produced during cement hydration to form additional cementitious compounds. This process enhances the concrete's strength and durability.

3) Reduction of Carbon Footprint: By replacing a portion of the cement with metakaolin, the carbon footprint of concrete production can be reduced. Cement production is a significant source of CO_2 emissions, so using metakaolin helps mitigate environmental impact.
4) Improved Performance: Concrete incorporating metakaolin exhibits improved performance characteristics, such as reduced permeability, increased resistance to chemical attack, and enhanced durability.

B. Fly ash

The cement production required to meet the current demand of the global construction industry significantly contributes to greenhouse gas emissions, accounting for approximately 7% of the total man-made emissions. This poses a serious environmental issue. An emerging solution to mitigate this impact is the development of geopolymers, which are influenced by various factors including:

1) Nature of the Source Material: The type of raw material used in the formation of geopolymers greatly affects their properties. Materials like fly ash, slag, and metakaolin are commonly used.
2) Type and Concentration of Alkaline Solution: The choice of alkaline activators, typically a combination of sodium or potassium hydroxides and silicates, determines the polymerization process and final properties of the geopolymer.
3) Curing Temperature and Method: Higher curing temperatures can accelerate the setting and strength development of geopolymers. Methods can include ambient curing or heat curing.
4) Period of Heat Curing: The duration for which heat curing is applied can influence the mechanical properties and durability of the geopolymer.
5) Water Content: The water-to-alkaline solution ratio affects the workability and strength of the geopolymer. Proper control of water content is crucial for optimal performance.
6) Rest Period: The time allowed for the geopolymer mixture to rest before curing can impact the setting time and final strength.

Additionally, the presence of calcium-containing compounds such as Portland cement (PC), calcium hydroxide (CH), and calcium oxide (CaO) significantly influences the setting time, workability, and compressive strength development of geopolymers.

II. LITERATURE REVIEW

Kunchapusuresh et al (2021) mechanical properties of geopolymer concrete and OPC concrete after exposure to elevated temperature (280c to 600 ^{0}c) were studied and compared to each other. In the present study, at 400°C temperature, the decreases of compressive strength of OPC concrete while air-cooled is 4% and 19% for water-cooled. For the geopolymer concrete is around 26% and 31%. Compare with air-cooled OPC specimen, despite the fact that there is a higher rate of strength decrease for GP concrete up to a temperature exposure of 200°C. After200°C, the strength loss decreases in geopolymer concrete when compared to OPC concrete up to 400°C.The strength loss is more at 400°C for OPC concrete, but in geopolymer concrete, the strength loss is less at 400°C, at 400°C the residual strength is nearly equivalent for both OPC concrete and geopolymer concrete. It might additionally be noticed that, while the rate of strength loss is nearly the equivalent for both the kinds of concrete between 400 °C and 600 °C. The geopolymer concrete when compared with OPC concrete there is a higher strength loss for geopolymer concrete at an early stage of temperature raise (200°C) in this research.At a temperature exposure above 400 °C, the un-reacted crystalline materials in geopolymer concrete get changed into shapeless state and experience polymerization. Accordingly, there is no further strength loss (compressive strength, tensile strength, flexural strength) in geopolymer concrete, OPC concrete keeps on losing its strength properties at a quicker rate past a temperature presentation of 600°C.

Mohd Mustafa Al Bakri Abdullah et al (2022) was examined the consumption of Ordinary Portland Cement (OPC) caused pollution to the environment due to the emission of CO 2 . As such, alternative material had been introduced to replace OPC in the concrete. Fly ash is a by-product from the coal industry, which is widely available in the world. Moreover, the use of fly ash is more environmental friendly and save cost compared to OPC. Fly ash is rich in silicate and alumina, hence it reacts with alkaline solution to produce aluminosilicate gel that binds the aggregate to produce a good concrete. The compressive strength increases with the increasing of fly ash fineness and thus the reduction in porosity can be obtained. Fly ash based geopolymer also provided better resistance against aggressive environment and elevated temperature compared to normal concrete. As a conclusion, the properties of fly ash-based geopolymer are enhanced with few factors that influence its performance.

III. METHODOLOGY

In this study, we explored the effects of varying the percentage of fly ash replacement to met kaolin in concrete mixtures. We experimented with six different replacement levels: 0%, 5%, 10%, 15%, 20%, and 25%. The objective was to evaluate how these changes impacted the physical and chemical properties of the concrete.

Table 1 Showing actual material quantity for $1m^3$

S.N	% Replacement	Fly ash Kg	Met kaolin Kg	Fine Aggregate Kg	Coarse Aggregate Kg
1	0	412	0	642	1008
2	5	391.4	20.6	642	1008
3	10	370.8	41.2	642	1008
4	15	350.2	61.8	642	1008
5	20	329.6	82.4	642	1008
6	25	309.0	103	642	1008

These materials work together to create a concrete that is strong, durable, and environmentally friendly, with a reduced carbon footprint compared to traditional Portland cement concrete. We calculate materials quantity as per our requirements.

- We take 15 mould of size 15cm *15cm* 15cm for single batch
- Then volume of one mould 15cm*15cm *15cm = $3375cm^3$
- In meter volume of single mould = $0.003375\ m^3$
- Volume of 15 mould 15* 0.003375 = $0.050625\ m^3$

Table 2 for M40 grade of concrete for materials required $0.050625\ m^3$

Fly ash	Fine Aggregate Kg	Coarse Aggregate Kg	water
$412kg/m^3$ X $0.050625m^3$ = 20.86kg	642 kg/m^3 * $0.050625m^3$= 32.50kg	$1008kg/m^3$*$0.050625m^3$= 51.03 kg	160 L/m^3*$0.050625m^3$ = 8.1 Lit

Solution Quantity calculation
Total molecular weight of NaOH = 23+16+1 = 40gm (Na= 22.99, O= 15.99, H=1)
1000ml (1 lit Water) → 40gm (NaOH) →1Molarity

For 1 Lit water
12.5M Required NaOH = 12.5*40 = 500gm
SMS take 50% Total weight of NaOH

But our experiment required of water 8.1Lit
Hence Required of NaOH = 8.1*500 = 4050gm
SMS = 4050/2 = 2025gm

IV. RESULT AND DISCUSSION

Geopolymer concrete (GPC) is an innovative material that offers an environmentally friendly alternative to conventional Portland cement concrete. It is made by activating aluminosilicate materials (like fly ash, slag, or metakaolin) with alkaline solutions. This discussion focuses on the results of various studies and the implications for the construction industry.

Compressive Strength: Studies have shown that geopolymer concrete can achieve comparable or even higher compressive strength than traditional Portland cement concrete. Depending on the mix design, curing conditions, and raw materials used, GPC can reach compressive strengths.

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Table 3 Compressive strength of concrete N/mm^2

Percentages Replacement	7 Days	28 Days
0	28.73	44.25
5	29.13	45.10
10	29.84	46.87
15	30.12	47.56
20	31.58	49.23
25	29.67	43.65

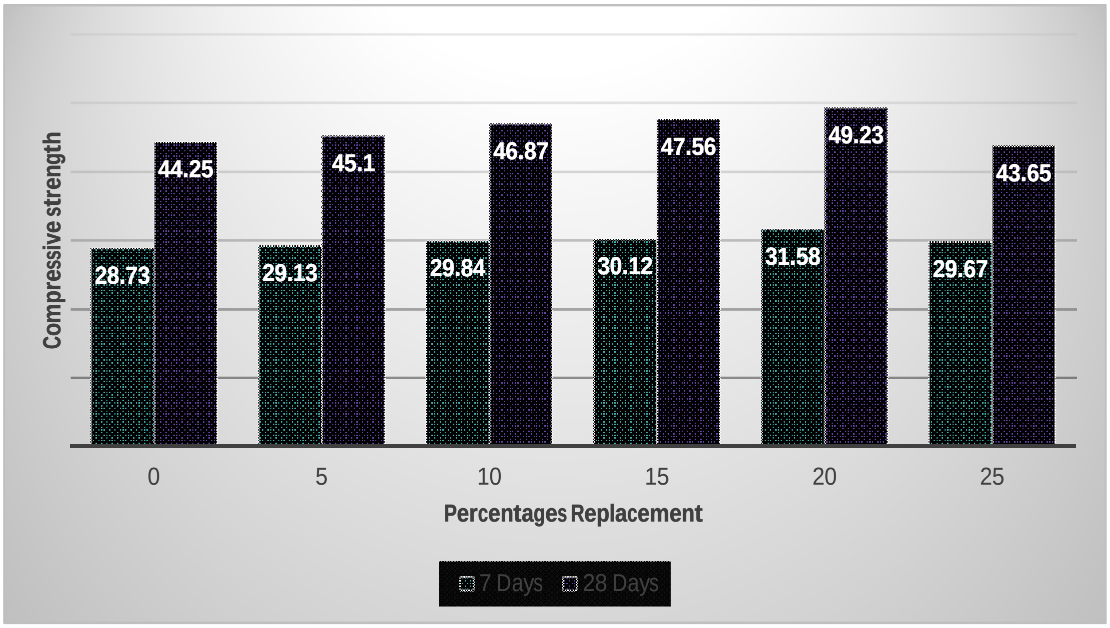

Figure 1 Compressive strength of concrete

Durability: GPC is highly resistant to chemical attacks, such as acid and sulfate attacks, which are common issues in aggressive environments. It also shows lower permeability and improved fire resistance compared to ordinary Portland cement (OPC) concrete. The test is carried out for 28 days. The specimens are immersed in a solution of 5% H_2SO_4 by weight. The durability is determined in terms of reduction in weight.

Table 4 Weight Reduction results

Percentages Replacement	Normal weight (Kg)	Reduced weight (kg)	% Reduction in weight
0	7.75	7.45	4.12
5	8.25	7.95	3.60
10	8.30	8.05	3.01
15	7.95	7.65	3.7
20	8.30	8.10	2.4
25	8.05	7.80	3.1

V. CONCLUSION

Geopolymer concrete presents a promising sustainable alternative to traditional concrete, with significant benefits in terms of strength, durability, and environmental impact. Ongoing research and development are needed to address the challenges of material consistency, workability, cost, and standardization to facilitate its widespread adoption in the construction industry.

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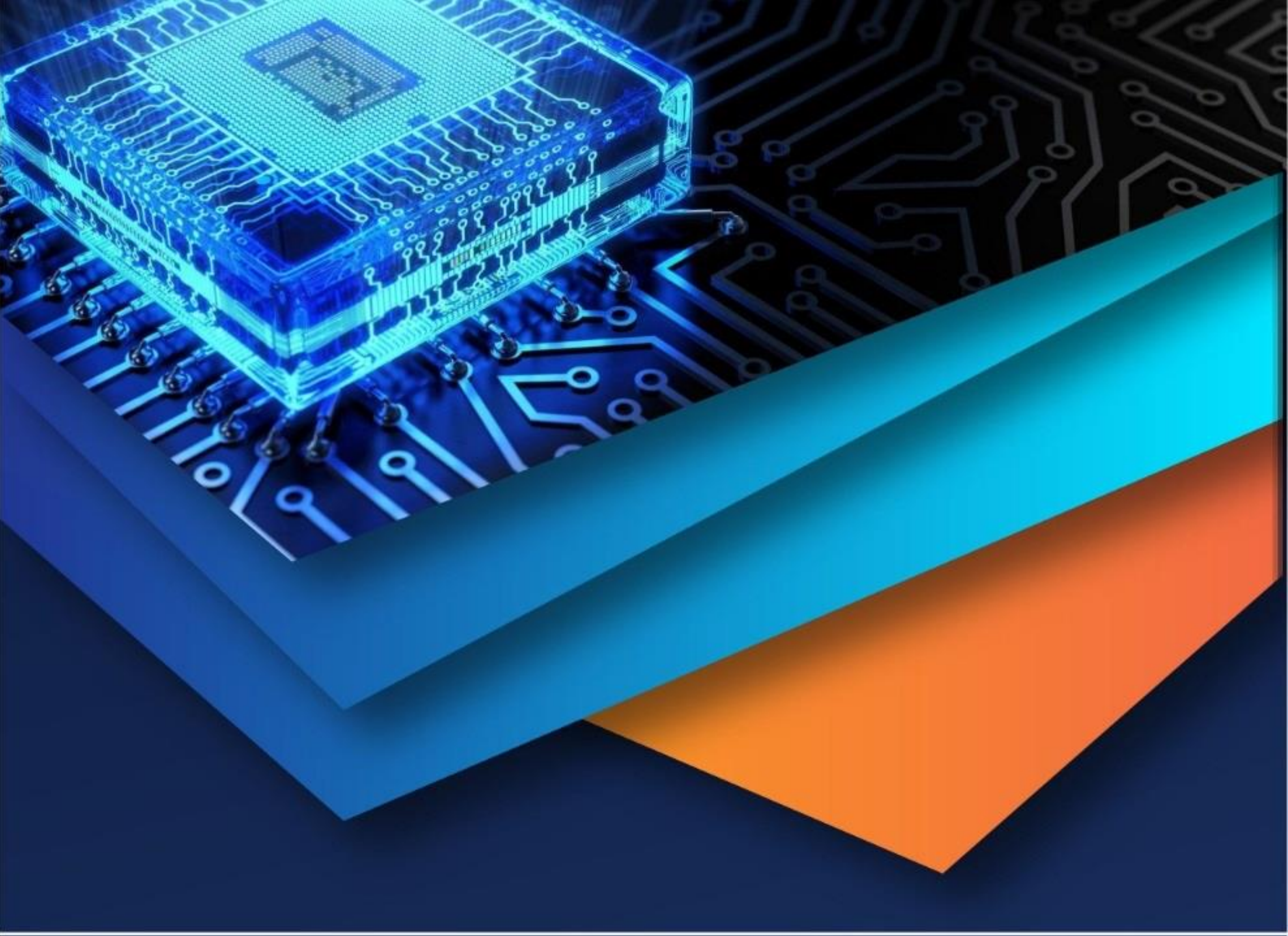

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