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Replacement of Cement with Geopolymer Material

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ABSTRACT: Geopolymer concrete represents a promising advancement in the field of construction materials. Its environmentally-friendly nature, excellent mechanical properties, and enhanced durability make it a compelling option for sustainable infrastructure development. As research and adoption continue to grow, geopolymer concrete has the potential to transform the construction industry and contribute to a more sustainable future. Concrete is second most used material in the world only after water. The rate of demand for concrete increasing exponentially day by day. Cement being major component used in concrete, producing cement is inevitable. Almost one tonne of CO₂ is released into the atmosphere for producing one tonne of cement i.e. 0.55 tonne due to the calcination process of lime and 0.40 ton due to consumption of fuel which shows negative impact on environment. In this project we are working to fully replace ordinary Portland cement with Geopolymer material.

KEYWORDS: Geopolymer, Portland cement, concrete.

I. INTRODUCTION

Geopolymer concrete is an innovative and environmentally-friendly alternative to traditional Portland cement-based concrete. It is a type of concrete that utilizes a Geopolymer binder instead of the commonly used cement binder. The Geopolymer binder is derived from industrial by-products such as fly ash, silica fume, and slag, which are rich in silicon and aluminum. The development of Geopolymer concrete stems from the need to reduce the carbon footprint associated with cement production. The manufacturing of traditional cement involves the high-temperature calcination of limestone, which releases a significant amount of carbon dioxide (CO₂), contributing to greenhouse gas emissions and climate change. Geopolymer concrete offers a solution by minimizing the use of Portland cement or eliminating it altogether. The geopolymerization process involves activating the raw materials, such as fly ash or slag, with an alkaline solution. This activates a chemical reaction that forms a three-dimensional polymeric network, resulting in a solid and durable binder. The resulting geopolymer binder has excellent mechanical properties, comparable or even superior to those of traditional concrete. Geopolymer concrete offers several advantages over Portland cement-based concrete. It has a significantly lower carbon footprint, with CO₂ emissions reduced by up to 80% during production. Geopolymer concrete also exhibits excellent chemical resistance, high compressive strength, and improved durability. It has a lower permeability, which leads to enhanced resistance against corrosion and deterioration. Additionally, geopolymer concrete has better fire resistance and can withstand higher temperatures without significant loss of strength. The application of geopolymer concrete is diverse, ranging from infrastructure projects to residential and commercial buildings. It can be used for foundations, beams, columns, and various structural elements. Geopolymer concrete has been successfully employed in road construction, precast elements, and repair and rehabilitation projects. Although geopolymer concrete offers numerous advantages, its widespread adoption is still in progress. Challenges include the need for standardized production methods, optimization of mix designs, and overcoming skepticism and resistance to change within the construction industry. However, ongoing research and development efforts aim to address these challenges and promote the use of geopolymer concrete as a sustainable and durable alternative to traditional concrete. Geopolymer concrete represents a promising advancement in the field of construction materials. Its environmentally-friendly nature, excellent mechanical properties, and enhanced durability make it a compelling option for sustainable infrastructure development. As research and adoption continue to grow, geopolymer concrete has the potential to transform the construction industry and contribute to a more sustainable future. Geopolymer concrete is a type of concrete that is produced by replacing traditional Portland cement with a geopolymer binder. It is an alternative to conventional concrete that offers several advantages in terms of durability, sustainability, and strength. The key ingredient in geopolymer concrete is the geopolymer binder, which is typically made from a combination of

aluminosilicate materials such as fly ash, slag, or metakaoline, along with an alkaline activator solution. These materials undergo a chemical reaction known as geopolymerization, which forms a three-dimensional polymer network that binds the aggregates together.

Advantages of Geopolymer

1. High Strength
2. Very Low Creep and Shrinkage
3. Resistant to Heat and Cold
4. Chemical Resistance

Disadvantages of Geopolymer Concrete

1. Difficult to Create
2. Pre-Mix Only
3. Geopolymerization Process is Sensitive

II. LITERATURE REVIEW

Manvendra Verma, Nirendra Dev, Ibadur Rahman, Mayank Nigam, Mohd. Ahmed and Javed Mallick Geopolymer [1], concrete (GPC) is a new material in the construction industry, with different chemical compositions and reactions involved in a binding material. The pozzolanic materials (industrial waste like fly ash, ground granulated blast furnace slag (GGBFS), and rice husk ash), which contain high silica and alumina, work as binding materials in the mix. Geopolymer concrete is economical, low energy consumption, thermally stable, easily workable, ecofriendly, cement less, and durable. GPC reduces carbon footprints by using industrial solid waste like slag, fly ash, and rice husk ash. Around one tone of carbon dioxide emissions produced one tone of cement that directly polluted the environment and increased the world's temperature by increasing greenhouse gas production. For sustainable construction, GPC reduces the use of cement and finds the alternative of cement for the material's binding property. So, the geopolymer concrete is an alternative to Portland cement concrete and it is a potential material having large commercial value and for sustainable development in Indian construction industries. The comprehensive survey of the literature shows that geopolymer concrete is a perfect alternative to Portland cement concrete because it has better physical, mechanical, and durable properties. Geopolymer concrete is highly resistant to acid, sulphate, and salt attack. Geopolymer concrete plays a vital role in the construction industry through its use in bridge construction, high-rise buildings, highways, tunnels, dams, and hydraulic structures, because of its high performance. It can be concluded from the review that sustainable development is achieved by employing geopolymer in Indian construction industries, because it results in lower CO₂ emissions, optimum utilization of natural resources, utilization of waste materials, is more cost-effective in long life infrastructure construction, and, socially, in financial benefits and employment generation.

B. Naga Vinay, A. Venkateswara Rao [2], Geopolymer concrete is an advanced material which is formed by long chains and networks of the inorganic molecule and feasible alternative to ordinary Portland cement which is useful in different forms of construction in civil infrastructure applications. Geopolymer materials are obtained from natural materials and industrial by-products. Percentage of the carbon dioxide evolved from the Geopolymer material such as GGBS and class C fly ash is very low. Geopolymer concrete has the fastest setting time rapid development in strength and the carbon dioxide releasing from the source material is very low. In this paper, it describes that alkaline activators such as sodium hydroxide (NaOH) and sodium silicate in different molarities will mix with the class F fly ash and GGBS in different proportions and compressive strength and flexural strength are determined in order to identify the new phase that formed in Geopolymer matrix.

Muhd Fadhil Nurrudin, Sani Haruna, Bashar S. Mohammed, and Ibrahim Galal Shaaban [3], Geopolymer concrete is a new approach of concrete production by exclusion of ordinary Portland cement entirely with pozzolanic material. Beside water, concrete is the largest consumed substances, which demand huge portion of Portland cement. During Portland cement manufacturing process, high emission of carbon dioxide (CO₂) is produced which results in polluting the surrounding environment. Moreover, a lot of energy is expended during cement production. Based on manufacturing situations, geopolymer concrete displays different behaviours and attributes. This paper succinctly discusses the different methods of curing of geopolymer concrete and figures out the best method of curing. Experimental findings revealed that condition of curing has a good influence on the mechanical properties of geopolymer concrete. Conventionally, ambience temperature curing of geopolymer concrete result in low strength development at an early age, while higher temperature curing results in significant strength improvement. Similarly,

extended curing time enhanced the geopolymerisation mechanism and achieved greater strength. However, longer duration of curing at an elevated temperature result in failure of the sample

S. Ponmalar Tagore [4], the success of an optimum design lies in the effective load transfer done by the bond forces at the steel-concrete interface. Self-Compacting Concrete is a new innovative concrete capable of filling intrinsic reinforcement and gets compacted by itself, without the need of external mechanical vibration. For this reason, it is replacing the conventional vibrated concrete in the construction industry. The present paper outlays the materials and methods adopted for attaining the self-compacting concrete and describes about the bond behaviour of this concrete. The bond stress-slip curve is similar in the bottom bars for both SCC and normal concrete whereas a higher bond stress and stiffness is experienced in the top and middle bars, for SCC compared to normal concrete. Also the interfacial properties revealed that the elastic modulus and micro-strength of interfacial transition zone [ITZ] were better on the both top and bottom side of horizontal steel bar in the SCC mixes than in normal vibrated concrete. The local bond strength of top bars for SCC is about 20% less than that for NC. For the bottom bars, however, the results were almost the same.

R. Anuradha, V. Sreevidyaa, R. Venkatasubramania and B.V. Ranganb [5], this experimental study is intended to identify the mix ratios for different grades of Geopolymer Concrete by trial and error method. A new Design procedure was formulated for Geopolymer Concrete which was relevant to Indian standard (IS 10262-2009). The Applicability of existing Mix Design was examined with the Geopolymer Concrete. Two kinds of systems were considered in this study using 100% replacement of cement by ASTM class F fly ash and 100% replacement of sand by M-sand. It was analysed from the test result that The Indian standard mix design itself can be used for the Geopolymer Concrete with some Modification.

Maria Teresa Gomes Barbosa & Souza Sánchez Filho [6], this experimental study is intended to identify the mix ratios for different grades of Geopolymer Concrete by trial and error method. A new Design procedure was formulated for Geopolymer Concrete which was relevant to Indian standard (IS 10262-2009). The Applicability of existing Mix Design was examined with the Geopolymer Concrete. Two kinds of systems were considered in this study using 100% replacement of cement by ASTM class F fly ash and 100% replacement of sand by M-sand. It was analysed from the test result that The Indian standard mix design itself can be used for the Geopolymer Concrete with some Modification

III.METHODOLOGY AND OBJECTIVE

Methodology

Cube of sizes for compression 150X150X150mm using M20 grade concrete Testing machine: compressive testing machine (CTM)

2. Cube of sizes for bond strength 150X150X150mm and steel bar of 12mm diameter using M20 grade concrete Testing machine: compressive testing machine (CTM)

3. Cube of sizes for flexural strength 100X100X500mm using M20 grade concrete Testing machine: flexural strength testing machine

Objective

1. To replace Ordinary Portland cement with GEOPOLYMER material
2. To compare compressive strength of Geopolymer concrete with conventional concrete
3. To compare flexural strength of Geopolymer concrete with conventional concrete
4. To compare bond behavior of Geopolymer concrete with conventional concrete



IV. MIX DESIGN

Design procedure for M20 grade Conventional Concrete

Table No 1: Mix calculation of Geopolymer concrete per m³

Geopolymer	Fly Ash	GGBS	Fine aggregate	Course aggregate	Water
1m ³	105	245	622.839	1394.44	112.93
0.033	3.465	8.085	20.55	46.016	3.726

Compressive Test Mix Design

Table No 2: Mix calculation for compressive test

Type of tests	Proportion M20 grade	Mix design Qty.	No. of cubes
Compressive Test (0.15x0.15x0.15m)	Conventional cubes	A)Cement -3.5Kg W/C 0.50 Water-1.7 LitFA-6.6Kg CA- 11.11Kg	3
	Geopolymer Concrete cubes 60-40 (GGBS-Flyash)	1) GGBS-1.89KgW/C 0.45 Flyash-1.26kg Water-1.01Lit FA-5.64Kg CA-12.63Kg NaOH-0.666Kg Na ₂ SiO ₃ -0.999Kg	3
	70-30 (GGBS-Flyash)	2)GGBS-2.205Kg W/C-0.45 Flyash-0.945kg FA-5.605Kg CA-12.54Kg Water-1.01Lit NaOH-0.666 Kg Na ₂ SiO ₃ -0.999 Kg	3

Flexural Test Mix Design

Table No 3: Mix calculation for flexural test

Type of tests	Proportion M20 grade	Mix design Qty.	No. of cubes
2 Flexural Test (0.1x0.1x0.5m)	Conventional cubes	A)Cement -5.91Kg W/C -0.50 Water-2.955Lit FA-11.03Kg CA-18.52Kg	3
	Geopolymer Concrete cubes 60-40 (GGBS- Flyash)	GGBS-3.15KgW/C-0.45 Flyash-2.955kg Water-1.69Lit FA-9.406Kg CA- 21.05Kg NaOH-1.11Kg Na ₂ SiO ₃ -1.66Kg	3



	70-30 (GGBS-Flyash)	GGBS-3.675Kg W/C-0.45 Flyash-1.575kg FA-9.34Kg CA-20.916Kg Water-1.69Lit NaOH-1.11Kg Na ₂ SiO ₃ -1.66Kg	3
	80-20 (GGBS-Flyash)	3)GGBS-4.2Kg W/C-0.45 Na ₂ SiO ₃ -0.999Kg Flyash-1.11kg FA-9.40Kg CA-21.05Kg Water-1.69Lit NaOH-1.11Kg	3

Bond Behaviour Mix Design

Table No 4: Mix calculation for bond behaviour test

Type of tests	ProportionM20 grade	Mix design Qty.	No.of cubes
3 Bond Behavior (0.15x0.15x0.15m)	Conventional Cubes	Cement -3.5KgW/C 0.50 Water-1.7 LitFA-6.6Kg CA-11.11Kg HYSD Steel bar12mm φ	3
	Geopolymer Concrete cubes 60-40 (GGBS- Flyash)	GGBS-1.89KgW/C 0.45 Flyash-1.26kg Water-1.01 LitFA-5.64Kg CA-12.63Kg NaOH-0.666Kg Na ₂ SiO ₃ -0.999Kg HYSD Steel bar12mm φ	3
	70-30 (GGBS-Flyash)	GGBS-2.205Kg W/C-0.45 Flyash-0.945kg FA-5.605Kg CA-12.54Kg Water-1.01Lit NaOH-0.666Kg Na ₂ SiO ₃ -0.999Kg HYSD Steel bar12mm φ	3
	80-20 (GGBS-Flyash)	GGBS-2.52KgW/C-0.45 Flyash-0.63kg FA-5.64Kg CA-12.635Kg Water-1.01Lit NaOH-0.666Kg Na ₂ SiO ₃ -0.999KgHYSD Steel bar12mm φ	3



Mix Procedure

Preparation of material

1. Material selection for –

A. Compression test and Flexural test:

First, river sand is taken passed from 4.75 mm sieve. Then course aggregate is taken passing through 20 mm size sieve. Cement of grade 43 is taken. For mixing potable water having pH value 7.15 is used. Chemical like sodium hydroxide and sodium silicate of

B. Bond stress: First, river sand is taken passed from 4.75 mm sieve. Then course aggregate is taken passing through 20 mm size sieve. Cement of grade 43 is taken. Steel bars of grade fe415 of diameter of 12 mm. For mixing potable water having pH value 7.15 is used. Chemical like sodium hydroxide and sodium silicate.

2. **Moulds:** The mould shall be of metal, preferably steel or cast iron, and stout enough to prevent distortion. It shall be constructed in such a manner as to facilitate the removal of moulded specimen without damage, and shall be so machined that, when it is assembled ready for use, the dimensions and internal faces shall be accurate within the following limits:

1. The height of the mould and the distance between opposite faces shall be specified size + 0.2 mm.
2. The angle between adjacent internal faces and between internal faces and top and bottom planes of the mould shall be 90 degree + 0.5 degree.
3. The internal faces of the mould shall be plane surface with a permissible variation of 0.03 mm

3. **Mixing:** For conventional block, calculated quantity of coarse aggregate, fine aggregate and cement is in mixer. First dry mix is done and then water is added to it and mixed for 2 minutes. Then the concrete mix is taken out. For Geopolymer, calculated quantity of coarse aggregate, fine aggregate, fly ash, GGBS, sodium hydroxide, and sodium silicate is in mixer as per the different proportion. First dry mix is done and then water is added to it and mixed for 2 minutes. Then the concrete mix is taken out.

4. **Casting:** The test specimens shall consist of concrete cubes of size (0.15 X 0.15 X 0.15) for conventional and for the bond stress test the specimen of same size cube with a single reinforcing bar embedded vertically along a central axis in each specimen. The bar shall project down for a distance of about 10 mm from the bottom face of the cube as cast and shall project upward from the top face whatever distance is necessary to provide sufficient length of bar to extent through the bearing blocks and the support of the testing machine and to provide an adequate length to be gripped for application of load.

5. **Vibrator:** The test specimen made as soon as practicable after mixing, and in such way to produce full compaction of concrete with neither segregation nor excessive laitance. Vibrator is to be used for compaction of concrete. While compacting by vibration, each layer shall be vibrated by means of vibrator until the specified condition is attained

6. **Curing:** After 24 hours of casting the prepared specimens are taken to curing in the water tank for 28 days.

7. **Testing:** The test specimens for different tests were made of cubes having a size of 150mm x 150mm x 150mm cast iron moulds were used. For each proportion three cubes were casted and tested at the age of 28 days.

After the material preparation the test was performed on UTM machine and the results are described in results and discussion chapter.

V. RESULTS AND DISCUSSION

1. COMPRESSIVE STRENGTH RESULT

Table No 5: Compressive strength of conventional concrete

Conventional block	Applied load (N)	Stress (N/mm ²)	Average stress(N/mm ²)
Specimen 1	450X10 ³	20	
Specimen 2	490X10 ³	21.78	21.48
Specimen 3	510X10 ³	22.67	
Geopolymer block	Applied load (N)	Stress (N/mm ²)	Average stress(N/mm ²)
60-40(GGBS-Flyash)			
Specimen 1	510X10 ³	22.68	
Specimen 2	480X10 ³	21.33	22.003
Specimen 3	495X10 ³	22.0	



Geopolymer block 70-30(GGBS-Flyash)	Applied load (N)	Stress (N/mm ²)	Average stress(N/mm ²)
Specimen 1	400X10 ³	17.78	
Specimen 2	450X10 ³	20.0	18.96
Specimen 3	430X10 ³	19.11	
Geopolymer block 80-20(GGBS-Flyash)	Applied load (N)	Stress (N/mm ²)	Average stress(N/mm ²)
Specimen 1	300X10 ³	13.33	
Specimen 2	310X10 ³	13.78	13.85
Specimen 3	325X10 ³	14.44	

Table No 6: Compressive strength of Geopolymer concrete

Proportion (GGBS-Flyash)	100-0	80-20	70-30	60-40
Avg. Strength (N/mm ²)	21.48	13.85	18.96	22.003

2. FLEXURAL STRENGTH RESULT

Table No 7: Flexural strength of conventional concrete

Conventional block	Applied load (N)	Flextural strength (N/mm ²)	Average Strength (N/mm ²)
Specimen 1	13X10 ³	5.2X10 ⁶	
Specimen 2	14X10 ³	5.6X10 ⁶	5.35X10 ⁶
Specimen 3	13X10 ³	5.2X10 ⁶	
Geopolymer block 60-40(GGBS-Flyash)	Applied load (N)	Stress (N/mm ²)	Average stress(N/mm ²)
Specimen 1	10.7X10 ³	4.28X10 ⁶	
Specimen 2	10.10X10 ³	4.04X10 ⁶	4.12X10 ⁶
Specimen 3	10.11X10 ³	4.04X10 ⁶	
Geopolymer block 70-30(GGBS-Flyash)	Applied load (N)	Stress (N/mm ²)	Average stress(N/mm ²)
Specimen 1	13.9X10 ³	5.56X10 ⁶	
Specimen 2	10.3X10 ³	4.12X10 ⁶	4.52X10 ⁶
Specimen 3	12.2X10 ³	4.8X10 ⁶	
Geopolymer block 80-20(GGBS-Flyash)	Applied load (N)	Stress (N/mm ²)	Average stress(N/mm ²)
Specimen 1	15X10 ³	6.0X10 ⁶	
Specimen 2	14.4X10 ³	5.76X10 ⁶	6.2 X10 ⁶
Specimen 3	15.5X10 ³	6.2X10 ⁶	

Table No 8: Flexural strength of Geopolymer concrete

Proportion (GGBS-Flyash)	100-0	80-20	70-30	60-40
Avg. Strength (N/mm ²)	5.35X10 ⁶	6.2 X10 ⁶	4.52X10 ⁶	4.12X10 ⁶

3. BOND STRESS RESULT (HYSD Steel bar 12 mm φ)

Table No 9: Bond stress of conventional concrete

Conventional block	Pull-out load (N)	Bond Stress (N/mm ²)	Average Bond Stress (N/mm ²)
Specimen 1	20X10 ³	3.78	
Specimen 2	26X10 ³	4.92	4.41
Specimen 3	24X10 ³	4.54	
Geopolymer block60-40(GGBS-Flyash)	Pull-out load (N)	Bond Stress (N/mm ²)	Average Bond Stress (N/mm ²)
Specimen 1	56X10 ³	10.61	
Specimen 2	71X10 ³	13.45	12.12



Specimen 3	65X10 ³	12.31	
Geopolymer block 70-30(GGBS-Flyash)	Pull-out load (N)	Bond Stress (N/mm ²)	Average Bond Stress (N/mm ²)
Specimen 1	63X10 ³	11.93	
Specimen 2	59X10 ³	11.17	10.98
Specimen 3	52X10 ³	9.85	
Geopolymer block 80-20(GGBS-Flyash)	Pull-out load (N)	Bond Stress (N/mm ²)	Average Bond Stress (N/mm ²)
Specimen 1	25X10 ³	4.73	
Specimen 2	35X10 ³	6.63	5.76
Specimen 3	31X10 ³	5.87	

Table No 10: Bond stress of Geopolymer concrete

Proportion (GGBS-Flyash)	100-0	80-20	70-30	60-40
Avg. Strength (N/mm ²)	4.41	5.76	10.98	12.12

VI. CONCLUSION

In this project we fully replace ordinary Portland cement with Geopolymer material. After analyzing our readings we can make the following conclusion

1. After compressive testing by observing the test and specimens we conclude that there is maximum strength is achieved by “60-40” proportion (GGBS –fly ash) with compared to conventional proportion.
2. After Pull out testing by observing the test and specimens we conclude that there is maximum strength is achieved by “60-40” proportion (GGBS –fly ash) with compared to conventional proportion.
3. After Flexural testing by observing the test and specimens we conclude that there is maximum strength is achieved by “80-20” proportion (GGBS –fly ash) with compared to conventional proportion.

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