EFFECT OF BINDER INDEX ON STRENGTH CHARACTERISTICS OF GEO POLYMER CONCRETE USING GGBS AND FLY ASH AS SOURCE MATERIALS

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Abstract: This abstract outlines a study investigating the mechanical properties of geopolymer concrete (GPC) produced using Class F Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) in varying proportions. Here's a structured breakdown of the key points: The o**bjectives of the research work, includes** the effect of FA and GGBS on the mechanical properties of geopolymer concrete. The **materials used are** Class F Fly Ash and GGBS mixed in five different ratios (FA0:GGBS100, FA25:GGBS75, FA50:GGBS50, FA75:GGBS25, FA100:GGBS0). The Alkaline activators used are Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH) with 8 Molarity. **Mechanical Properties Studied** are **Compressive Strength, Split Tensile Strength, Flexural Strength.** All mechanical property tests were conducted at ambient room temperature. Introduction of a "Binder Index" parameter to quantify the influence of molarity and the FA-to-GGBS ratio on the mechanical properties of GPC.

Key words: Geopolymer Concrete, Fly Ash, Ground Granulated Blast Furnace Slag, Compressive Strength, Split Tensile Strength and Flexural Strength, Binder Index, Ambient temperature.

1 .INTRODUCTION

The production of Portland cement is energy-intensive and contributes significantly to carbon dioxide (CO_2) emissions, a primary driver of global warming. For every ton of Portland cement produced, approximately one ton of CO_2 is released into the atmosphere. This relationship highlights the role of the cement industry in contributing to climate change(1). As global warming and its impacts become more pressing concerns, researchers and industry professionals are seeking environmentally sustainable alternatives to Portland cement(2). Efforts to address these challenges have focused on supplementing or replacing Portland cement with alternative binders, including supplementary cementitious materials (SCMs) such as fly ash, silica fume, granulated blast furnace slag, rice husk ash, and metakaolin. A promising alternative is the use of alkali-activated binders, which utilize industrial by-products rich in silicate and alumina content. geopolymers," referring to binders created through the polymerization reaction of alkaline solutions with silicon and aluminum from geological or industrial by-product sources. This innovative binder system offers a pathway for producing eco-friendly construction materials. Among the most commonly studied materials for geopolymer binders are Class F fly ash and Ground Granulated Blast Furnace Slag (GGBS)(3-4).
Research into geopolymer pastes and concretes has grown significantly, with numerous studies highlighting their potential as sustainable and durable construction materials. Building upon these prior investigations, the present study examines the influence of varying proportions of fly ash, GGBS, and alkaline solution molarity on the mechanical properties of geopolymer concrete.
To better understand the contribution of different binders to the performance of geopolymer concrete, a novel parameter, the Binder Index, is introduced. This parameter quantifies the effect of binder composition on the strength properties of geopolymer concrete cured at ambient room temperature.
This research aims to expand the knowledge base for geopolymer concrete, paving the way for its practical application as an eco-friendly alternative to traditional Portland cement-based materials.

2. EXPERIMENTAL INVESTIGATION: The experimental program was designed to evaluate the mechanical properties of geopolymer concrete (GPC) by testing its compressive strength, split tensile

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strength, and flexural strength. The details of the materials, mix proportions, specimen preparation, and testing methods are summarized as follows: **Specimen Preparation and Dimensions: Cubes**: 100 mm × 100 mm × 100 mm for compressive strength testing. **Cylinders**: 100 mm diameter × 200 mm height for split tensile strength testing. **Prisms**: 100 mm × 100 mm × 500 mm for flexural strength testing. **Binder Proportions:** Five different Fly Ash (FA) to GGBS ratios were used: 100:0 (FA100:GGBS0), 75:25 (FA75:GGBS25), 50:50 (FA50:GGBS50), 25:75 (FA25:GGBS75), 0:100 (FA0:GGBS100)

Mix Design Parameters: Alkaline Liquid-to-Fly Ash Ratio: 0.36, **Fine Aggregate-to-Total Aggregate Ratio**: 32%

Alkaline Solution: A constant molarity of 8 M was maintained throughout the study. The solution consisted of a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3)

Ambient room temperature curing was employed for all specimens, without the use of heat curing. Strength properties were tested at two curing periods, **7 days & 28 days**

Testing Approach : For each mix proportion, three identical specimens were cast and tested to ensure reproducibility and reliability of the results. The mechanical properties tested included: **Compressive Strength** (cubes), **Split Tensile Strength** (cylinders), **Flexural Strength** (prisms). This systematic experimental approach allows for a comprehensive evaluation of the effect of varying FA-to-GGBS ratios and ambient curing duration on the mechanical performance of geopolymer concrete.

2.1 The materials used in the experimental investigation are as follows:

Fly Ash (FA), Source: Obtained from the Kothagudem Thermal Power Station, Bhadradri Kothagudem District, Telangana, India. , **Specific Gravity**: 2.17

Ground Granulated Blast Furnace Slag (GGBS): Source: Supplied by Blue Way Exports, Vijayawada, Andhra Pradesh, India, **Specific Gravity**: 2.90

Chemical Composition: Detailed chemical compositions of Fly Ash and GGBS are provided in **Table 1** (not included here but presumably detailed in the original study).

Fine Aggregate (Sand): Source: Natural River sand, confirming to **Grading Zone II** as per IS 383:1970 standards. **Specific Gravity**: 2.32, **Fineness Modulus**: 2.81

Coarse Aggregate: Size: Maximum size of 12 mm., **Source**: Local source.

Alkaline Activator Solution : Sodium Hydroxide (NaOH): The molar solution used for activation has a molarity of **8 M**.

- **Preparation**: Sodium hydroxide pellets were dissolved in water to prepare the solution. Specifics regarding the pellets used are given in **Table 2** (not included here).
- The sodium hydroxide solution was mixed with sodium silicate (Na_2SiO_3) solution.
- **Sodium Silicate to Sodium Hydroxide Ratio**: 2.5:1, as per prior research (referenced as [5]).
- The combined alkaline solution was stored for **24 hours at room temperature** before use in casting the geopolymer concrete.

Superplasticizer

- **Type**: Conplast SP-430.
- **Purpose**: Used to achieve the desired workability of the mix.

This section outlines the key materials and their properties used in the study, ensuring that the mix design and activation process for geopolymer concrete were well-controlled for consistent results.

Table 1. Chemical Composition of Fly Ash and GGBS percentage by mass.

Material	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	Na_2O	LOI
Fly ash	60.12	26.63	4.22	0.32	4.1	1.21	0.2	0.85
GGBS	34.16	20.1	0.81	0.88	32.8	7.69	nd	.

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Table 2. Materials used for NaOH solution preparation.

Description	8 moles/L
Sodium hydroxide pellets , (grams)	262
Potable Water (grams)	738

2.2 Mix proportions: The Geo Polymer Concrete mix proportions are shown in table 3.

Table 3. Geo Polymer Concrete mix proportions.

FA:GGBS	Molarity(M)	Geo Polymer Concrete mix proportions (Kg/m^3)						
		Coarse Aggregate	Fine Aggregate	Fly Ash	GGBS	NaOH Solution	Sodium Silicate	Super Plasticizer(2% of the Binder)
100:0	8	1100	517.45	575.2	0	59.10	148.25	11.50
75:25	8	1100	517.45	431.4	143.8	59.10	148.25	11.50
50:50	8	1100	517.45	287.6	287.6	59.10	148.25	11.50
25:75	8	1100	517.45	143.8	431.4	59.10	148.25	11.50
0:100	8	1100	517.45	0	575.2	59.10	148.25	11.50

2.3 Casting of Geo Polymer Concrete specimens:

The casting process for the geopolymer concrete (GPC) specimens involved several steps to ensure uniform mixing and proper compaction, as outlined below:

Mixing Process

1. **Dry Mixing**:
    - The solid constituents, including aggregates and fly ash, were dry mixed for about **three minutes** to ensure uniformity.
2. **Liquid Mixing**:
    - The alkaline solution, water, and superplasticizer were pre-mixed separately. This mixture was then added to the solids.
3. **Wet Mixing**:
    - The wet mixing continued for another **four minutes**, resulting in a cohesive mixture with a dark color and shiny appearance.

The fresh geopolymer concrete had high cohesiveness, and its workability was assessed using the conventional **slump test**.

Compaction and Molding

- **Compaction**:
    - Fresh concrete was compacted in the molds by applying **25 manual strokes per layer** (three equal layers) and then subjected to **compaction on a vibration table** for **10 seconds** to remove air voids and ensure uniform density.
- **Molding**:
    - The freshly mixed geopolymer concrete was poured into molds for cubes, cylinders, and prisms.

Demolding and Curing

- **Demolding**:
    - The specimens were demolded after **24 hours** and then kept for **ambient curing**.
- **Curing Duration**:
    - Specimens were cured for two different periods: **7 days** and **28 days** at room temperature.

Testing of Specimens

The GPC specimens were tested for different mechanical properties as follows:

- **Compressive Strength**: Tested using **cubes** on a Universal Testing Machine (UTM) with a capacity of 1000 kN.

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- **Split Tensile Strength**: Tested using **cylinders** on the same UTM.
- **Modulus of Rupture (Flexural Strength)**: Tested using **prisms** under two-point loading.

The tests were conducted by gradually increasing the load at a constant rate until failure occurred. The maximum loads applied to each specimen were recorded according to **IS 516-1956**.

Specimen Details

- A total of **30 cubes**, **30 cylinders**, and **30 prisms** were cast using various **GGBS-to-Fly Ash ratios** and **8 Molar alkaline activator** solution.
- Three identical specimens were cast for each variation and tested at **7 days** and **28 days** curing periods.

Binder Index (Bi)

The **Binder Index (Bi)** was introduced to quantify the combined effect of the **GGBS to Fly Ash ratio** and the **molar concentration of the alkaline activator**. It is calculated using the formula:
Binder Index(Bi)=Molarity×(GGBSGGBS+Fly Ash)(Eq. 1)\text{Binder Index} (Bi) = \text{Molarity} \times \left(\frac{\text{GGBS}}{\text{GGBS} + \text{Fly Ash}} \right) \quad \text{(Eq. 1)}Binder Index(Bi)=Molarity×(GGBS+Fly AshGGBS)(Eq. 1)
This parameter helps study the influence of the binder composition on the mechanical properties of geopolymer concrete.
The experimental results, as detailed in **Table 4**, provide insight into the effect of varying binder compositions and curing periods on the strength characteristics of geopolymer concrete.

Table 4. Compressive Strength, Split tensile Strength and Modulus of Rupture values for GPC
The variation of Compressive strength, Split tensile Strength and Modulus of Rupture with GGBS to

Fly Ash : GGBS	Binder Index(Bi)	Compressive Strength (Mpa)			Split Tensile Strength (Mpa)			Modulus of Rupture (Mpa)		
		7D	28D	7D/28D	7D	28D	7D/28D	7D	28D	7D/28D
100:0	0	2.95	8.8	0.33	0.06	0.24	0.25	0.70	0.94	0.74
75:25	2	20.2	32.4	0.62	1.57	1.94	0.80	1.60	2.25	0.71
50:50	4	27.0	36.0	0.75	2.07	2.55	0.81	3.78	4.89	0.77
25:75	6	42.2	53.0	0.79	2.64	3.49	0.75	4.50	6.2	0.72
0:100	8	60.0	72.0	0.83	3.10	4.32	0.71	5.78	7.31	0.79

fly ash proportions are shown in fig 1, fig 2 and fig 3.

Fig 1. Effect of GGBS to Fly ash ratio on Compressive Strength of GPC

Fig 2.Effect of GGBS to Fly ash ratio on Split Tensile Strength of GPC

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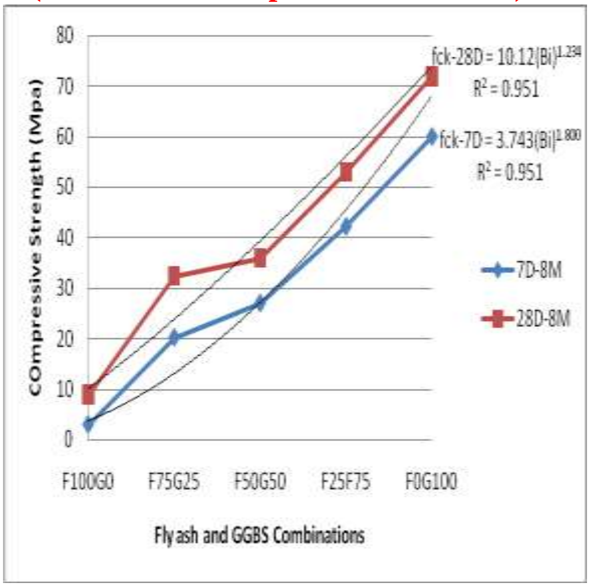


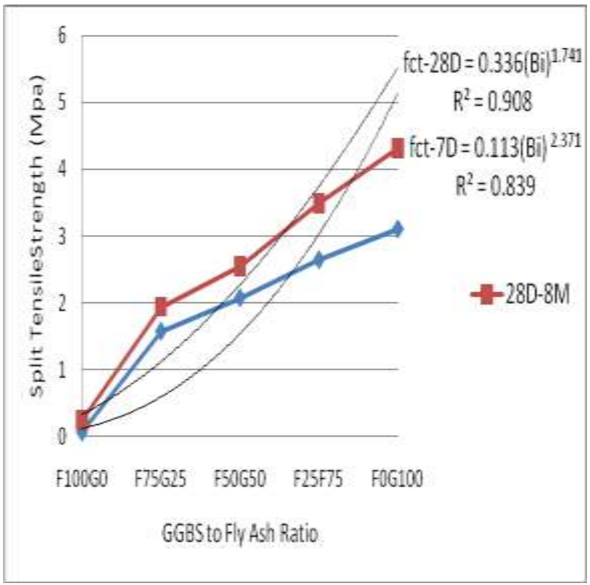
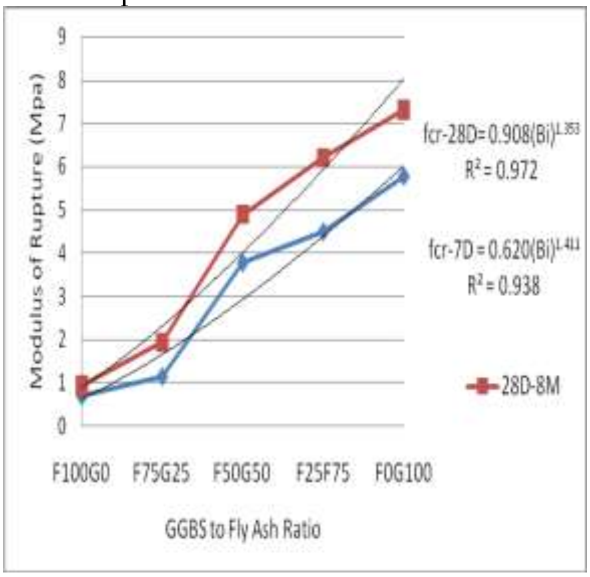


Fig 3. Effect of GGBS to Fly ash ratio on Modulus of
Rupture of GPC



The Compressive strength, Split Tensile strength and Modulus of Rupture for Geo Polymer Concrete are increased with increase in GGBS proportion and the increase in stength is more beyond GGBS to Fly ash ratio 1.

The effect of binder index on split tensile strength, Modulus of rupture and Compressive strengths are shown in fig 4, 5 , 6.

Fig 4. Effect of Binder Index on Split Tensile Strength , Fig5. Effect of Binder Index on Split Tensile Strength ,
Modulus of Rupture of GPC. Modulus of Rupture of GPC.

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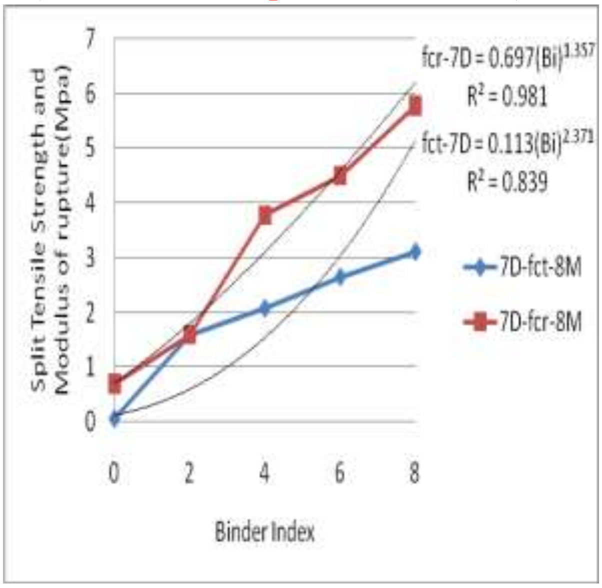


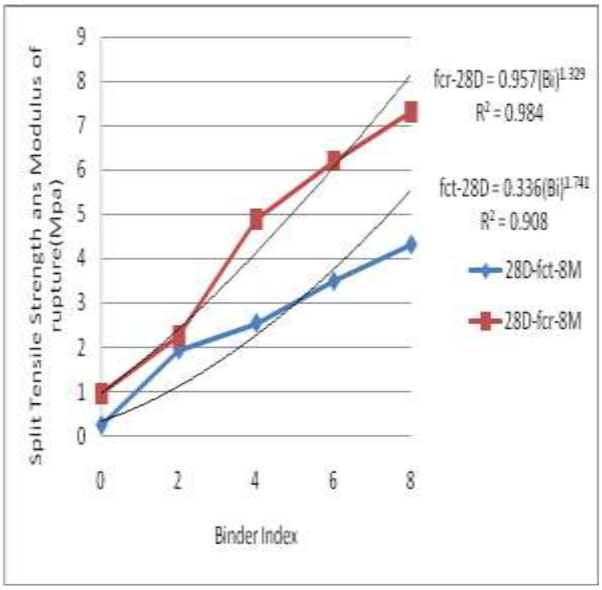
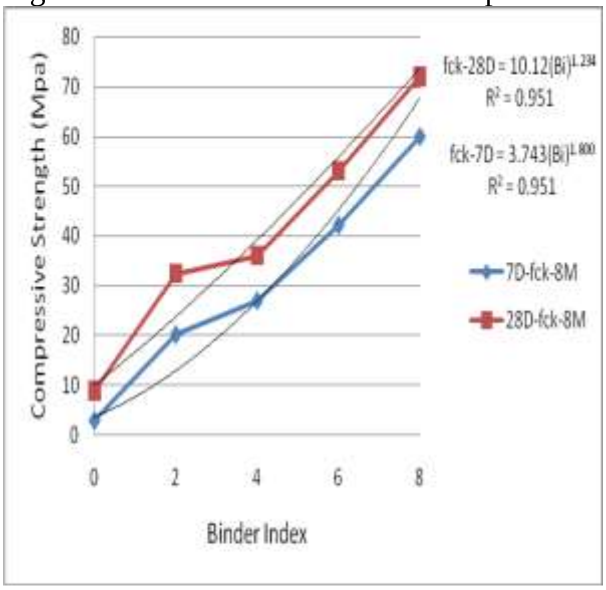


Fig 6. Effect of Binder Index on Compressive Strength of GPC.



The Compressive strength, Split Tensile strength and Modulus of Rupture for Geo Polymer Concrete are increased with increasing Binder index, and the increase in more after Binder index ratio 4.

5. Conclusions

1. Based on the experimental investigation, the following conclusions were drawn regarding the mechanical properties of geopolymer concrete (GPC):
2. **Effect of GGBS Proportion**:
3. The **compressive strength**, **split tensile strength**, and **modulus of rupture** of geopolymer concrete (GPC) increased as the proportion of **GGBS** in the mix was increased. This indicates that GGBS plays a significant role in enhancing the strength properties of GPC.
4. **Rate of Strength Gain**:
5. The rate of gain in **compressive strength**, **split tensile strength**, and **flexural strength** was **very fast** at the **7-day curing period**. However, the rate of strength development reduced as the curing period increased beyond 7 days. This highlights the rapid early-age strength development of GPC.
6. **Influence of Binder Index**:
7. The strength of geopolymer concrete increased with the **Binder Index (Bi)** value. The strength gain became more pronounced when the **Binder Index** exceeded a value of **4**. This

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suggests that a higher Binder Index leads to a more effective activation of the geopolymer binder, enhancing the material's mechanical properties.

8. **No Need for Heat Curing**:
9. Geopolymer concrete made with fly ash and GGBS combinations does not require **heat curing** to achieve desirable strength. This makes GPC a viable and energy-efficient alternative to traditional concrete, as it can cure effectively at ambient room temperature.
10. **Strength Improvement Beyond a Certain GGBS:FA Ratio**:
11. The **compressive strength**, **split tensile strength**, and **modulus of rupture** of GPC increased with higher proportions of GGBS. The strength improvement was more pronounced when the **GGBS to Fly Ash ratio** exceeded **1**, indicating that beyond this point, GGBS contributes significantly to further enhancing the material's strength.
12. These conclusions emphasize the potential of GPC, particularly with higher GGBS content, as a sustainable and high-performance alternative to conventional concrete.

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