Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 10, October: 2022

RESEARCH STUDY ON EFFECT OF GEOPOLYMER BINDER INDEX ON MODULUS OF RUPTURE OF FLY ASH, GGBS BASED GEOPOLYMER CONCRETE.

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ABSTRACT: *This study investigates the impact of Binder Index1 on the Modulus of Rupture in Fly Ash-based Geopolymer Concrete (GPC). The unit weight of the GPC is considered to be 2400 kg/m³. Various combinations of Fly Ash and Ground Granulated Blast Furnace Slag (GGBS) were used in the following proportions: 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, and 20:80, with an 8M alkaline molar activator. The ratio of alkaline liquid to fly ash was set at 0.36, and the fine aggregate to total aggregate ratio was maintained at 32%. The sodium silicate to sodium hydroxide solution ratio was kept at 2.5. Three identical specimens were cast for each combination and tested after 7 and 28 days of ambient curing. The variations in the Modulus of Rupture with respect to the Binder Index are presented and analyzed.*

Key words: *Geopolymer Concrete (GPC), Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Modulus of Rupture (fcr), Binder Index (B_i), 7 days (7D), 28 days (28D), Ambient temperature.*

1. INTRODUCTION

After water, concrete is the most widely used material globally, with Ordinary Portland Cement (OPC) being the primary binder for concrete production. However, the production of OPC involves significant energy consumption, including the calcination of limestone and the combustion of fossil fuels, resulting in considerable environmental concerns. The global availability of fly ash presents an opportunity to utilize this by-product from coal combustion as a partial replacement for OPC in concrete production. When combined with Ground Granulated Blast Furnace Slag (GGBS), the need for heat curing can be reduced.

In 1978, Davidovits proposed that binders could be formed through a polymeric reaction between alkaline liquids and the silicon and aluminum content in geological or by-product materials like fly ash and rice husk ash. He coined the term "geopolymers" for these binders. Later, Palomo et al. suggested that pozzolans such as blast furnace slag could be activated with alkaline liquids to create a binder, potentially replacing OPC entirely in concrete. In this process, the key components activated are silicon and calcium from the blast furnace slag, leading to the formation of a C-S-H gel during hydration. This research focuses on examining the effect of Binder Index on the Modulus of Rupture in Fly Ash-based Geopolymer Concrete (GPC).

2. **EXPERIMENTAL INVESTIGATION:** The experimental program involved determining the Modulus of Rupture strength of Geopolymer Concrete (GPC) by casting and testing prisms with dimensions of 100 mm x 100 mm x 500 mm. Seven different fly ash (FA) to Ground Granulated Blast Furnace Slag (GGBS) proportions were used: 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, and 20:80. The alkaline liquid content to fly ash ratio was set at 0.36, and the fine aggregate to total aggregate ratio was maintained at 32%. An 8 molar solution was used consistently throughout the study. For each mix variation, three identical specimens were cast and tested after 7 and 28 days of ambient curing.

2.1 MATERIALS: Fly ash was sourced from the Kothagudem Thermal Power Station, Bhadradri Kothagudem District, Telangana, India, while Ground Granulated Blast Furnace Slag (GGBS) was supplied by Blue Way Exports from Vijayawada, Andhra Pradesh, India. The specific gravities of the fly ash and GGBS were found to be 2.17 and 2.90, respectively. The chemical compositions of both materials are provided in Table 1. Natural river sand, conforming to grading zone II of IS 383:1970, was used, with a specific gravity of 2.32 and a fineness modulus of 2.81. Coarse aggregate of a maximum size of 20 mm was obtained from a local source. An 8-molarity sodium hydroxide solution was prepared using sodium hydroxide pellets, as detailed in Table 2. The sodium hydroxide solution was then mixed with sodium silicate solution, maintaining a ratio of 2.5:1. The resulting mixture was stored at room temperature for 24 hours before casting. To achieve the desired workability, the superplasticizer Conplast SP-430 was added.

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	.

Table 2. Materials used for NaOH solution preparation.

	8 moles/L
Sodium hydroxide pellets, (grams)	262

Potable Water (grams)	738

2.1 MIX PROPORTIONS: The Geo Polymer Concrete mix proportions are shown in Table 3.

Table 3. Geo Polymer Concrete mix proportions.

FA:GGBS	Geo Polymer Concrete mix proportions (Kg/m^3)						
	Coarse Aggregate	Fine Aggregate	Fly Ash	GGBS	NaOH Solution	Sodium Silicate	SP
80:20	1100	517.45	460.16	115.04	59.10	148.25	11.50
70:30	1100	517.45	402.64	172.56	59.10	148.25	11.50
60:40	1100	517.45	345.12	230.08	59.10	148.25	11.50
50:50	1100	517.45	287.6	287.6	59.10	148.25	11.50
40:60	1100	517.45	230.08	345.12	59.10	148.25	11.50
30:70	1100	517.45	172.56	402.64	59.10	148.25	11.50
20:80	1100	517.45	115.04	460.16	59.10	148.25	11.50

2. 2 CASTING OF GEO POLYMER CONCRETE SPECIMENS:

The solid components of the GPC, specifically the aggregates and fly ash, were dry mixed for approximately three minutes. The liquid components, including the alkaline solution, water, and superplasticizer, were premixed and then added to the solids. Wet mixing continued for an additional four minutes. The resulting fresh GPC was dark in color with a shiny appearance, and the mixture was highly cohesive. The workability of the fresh concrete was assessed using the conventional slump test. Compaction in the molds was achieved by applying 25 manual strokes per layer in three equal layers, followed by 10 seconds of vibration on a compaction table. After 24 hours, the molds were demolded, and the samples were kept for ambient curing.

The GPC prisms were tested for modulus of rupture under two-point loading using a Universal Testing Machine with a 1000 kN capacity. The load was applied gradually at a constant rate until failure, with maximum loads recorded for each specimen according to IS 516-1956[6]. Three identical specimens for each variation were cast and tested after 7 and 28 days of ambient curing. A total of 42 prisms, using different FA to GGBS ratios and 8 Molar alkaline activators, were cast and tested at the 7 and 28-day marks. The test results are provided in Table 4. The Binder Index (Bi) was used to evaluate the combined effects of the GGBS to (GGBS + fly ash) ratio and molarity[8].

Binder Index = Molarity x [GGBS / (GGBS + Fly Ash)] ......equation (1)

3.0 RESULTS AND DISCUSSIONS

Table 4. Modulus of Rupture values for GPC

S.No	FA: GGBS	Molarity	Binder Index	Modulus of Rupture (Mpa)	
				7D	28D
1	80:20	8 M	1.6	1.82	2.89
2	70:30		2.4	2.18	3.14
3	60:40		3.2	3.13	5.50
4	50:50		4	3.80	5.69
5	40:60		4.8	4.78	6.90
6	30:70		5.6	5.24	7.92
7	20:80		6.4	6.88	8.95

The variation of Modulus of rupture with Binder index is shown in below.

Industrial Engineering Journal
ISSN: 0970-2555
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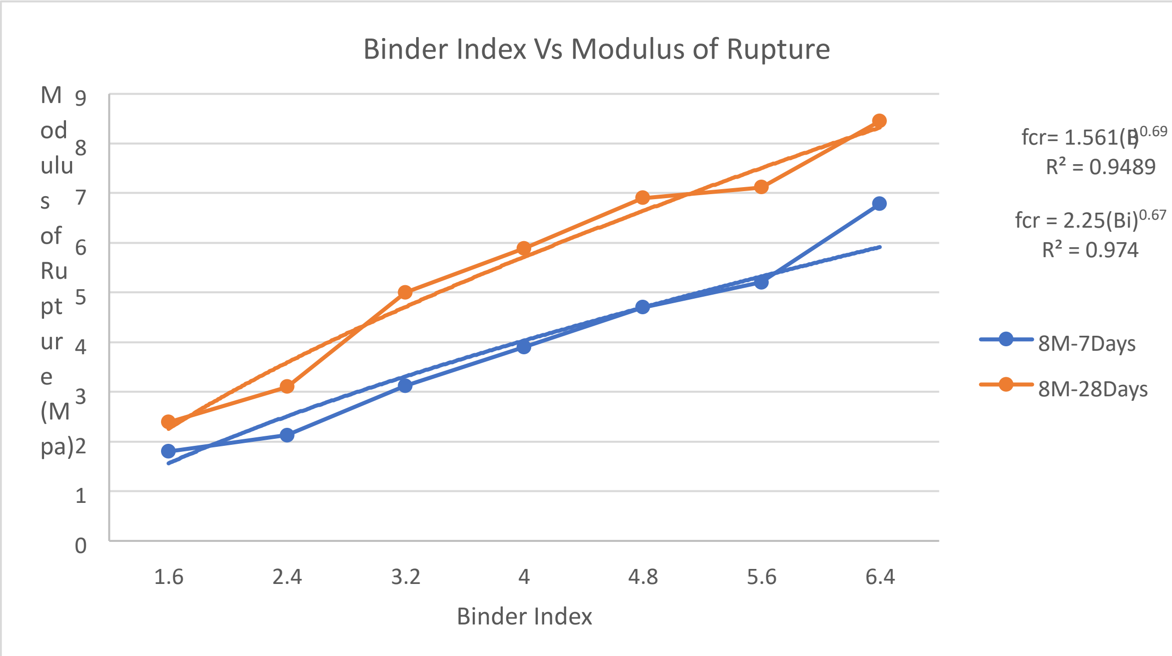

Fig 1. Variation of Modulus of rupture with Binder Index

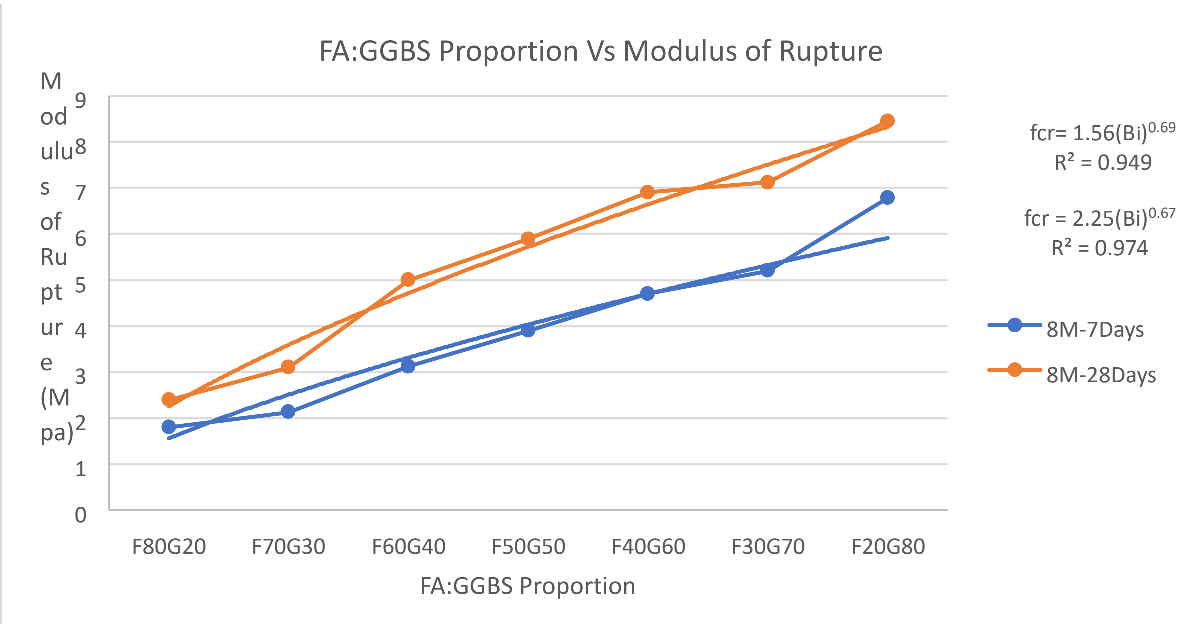

Fig 2. Variation of Modulus of rupture with FA: GGBS Proportion

From Figure 1, it is evident that the modulus of rupture at both 7 and 28 days increases as the Binder Index values rise.

Figure 2 shows that the modulus of rupture at 7 and 28 days also increases with a higher proportion of GGBS in the mix.

As seen in Table 3, for a constant molarity of the alkaline activator (8M), the modulus of rupture at both 7 and 28 days increases with a higher GGBS content in the mix.

The following best-fit equations illustrate the relationship between the modulus of rupture of GPC at 7 and 28 days of ambient curing and the Binder Index (Bi), along with the corresponding correlation coefficient (R^2).

The following equations represent the relationship between the modulus of rupture and Binder Index (Bi):

For 7 days:

fcr - 7D = 1.57 (Bi)^{0r7}, with $R^2 = 0.989$ .....(Equation 2)

For 28 days:

fcr - 28D = 2.26 (Bi)^{0p7}, with $R^2 = 0.984$ .....(Equation 3)

4.0 CONCLUSIONS

Based on the experimental results obtained in this study, the following conclusions can be made:

1. The modulus of rupture of Geopolymer concrete increases with a higher proportion of GGBS in the mix.
2. The strength gain of Geopolymer concrete is rapid during the 7-day curing period, with the rate of gain slowing down as the curing age increases.
3. The strength of Geopolymer concrete improves with an increase in Binder Index value.
4. A combination of fly ash and GGBS can be used to produce Geopolymer concrete without the need for heat curing.
5. The Binder Index, which incorporates the effects of GGBS, fly ash, and molarity, can be used to predict the modulus of rupture of Geopolymer concrete.

5.0 REFERENCES

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