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Effect of Fly Ash–GGBFS Blend Ratio on Mechanical Properties of Geopolymer Concrete

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Abstract:

Geopolymer concrete (GPC) has become a viable alternative to the normal Portland cement concrete, in terms of its lower carbon footprint and good use of industrial wastes. The experiment research paper examines the mechanical characteristics of M30 grade GPC prepared with a binary mixture of low-calcium fly ash and ground granulated blast furnace slag (GGBFS) in a different ratio and activated by an 8 molar (8 M) alkaline solution. Alkaline activators were NaOH and Na silicate. Mechanical properties such as compressive strength, split tensile strength and flexural strength were measured at various ages, that is, curing ages. The findings reveal that the chosen mix proportion will give the target M30 strength with acceptable early-age and long-term performance. GGBFS greatly contributed to the early strength development since it contains calcium and fly ash helped in the long-term strength increase and better workability. The experiment affirms that M30 grade geopolymer concrete with 8 M molarity and fly ash-GGBFS ratio of 60:40 can be used in the structural works.

Keywords: Geopolymer concrete; Fly ash; GGBFS; Alkaline activation; Mechanical properties; M30 grade.

1. INTRODUCTION

Construction industry belongs to the important sources of carbon dioxide emissions in the world because of the significant level of use of ordinary Portland cement (OPC), the production of which is energy-consuming and causes a considerable amount of CO2 emissions into the atmosphere. The current trend of increased focus on sustainable development and environmentally friendly construction practices has led to an increased demand in coming up with alternative binder systems that may enable a reduction in the use of OPC but at the same time may not affect the structural performance. Geopolymer concrete, in this regard, has become one of the potentially sustainable construction materials, as it applies industrial wastes and removes the traditional cement application (Hussin et al., 2014; Ojha and Aggarwal, 2021; Rihan et al., 2024).

Geopolymer concrete is prepared by the alkaline activation of materials alumino- silicate rich like fly ash, ground granulated blast furnace slag (GGBFS), metakaolin and other industrial wastes. Geopolymerization process entails dissolution of silica and alumina in an alkaline environment, which is polycondensed to form a three-dimensional polymeric structure. This network enhances high mechanical characteristics, high resistance to chemical assault, and better strength than normal OPC-based concrete(Neupane, 2018; Sambucci et al., 2021; Sarker, 2008)

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The GPC performance is highly dependent on various parameters such as the source of materials and their proportion, the alkaline activator content, the molarity of the alkaline solution, the curing regime and the properties of the aggregate. Among them, the molarity of alkaline activator is very critical in regulating the dissolution of silica and alumina species, which has a direct impact on the rate of geopolymerization and subsequent mechanical properties. In the earlier research, it was found that the molarity of alkaline solution within the 8-12 M range is suitable to produce structural GPC with sufficient workability and strength (Dineshkumar & Umarani, 2020; Sunarsih et al., 2023; Wong et al., 2021).

Herein related to the current research, the formulation of the M30 grade GPC, with the use of an 8 molar alkaline solution and a binary system of binders in a ratio of 60: 40 (fly ash and GGBFS) is under consideration. The choice of this combination is aimed at getting a balance between sustainability, the development of early-age strength, and long-term mechanical performance when subjected to ambient curing conditions. The main goal of this study is to decide the mechanical properties, compressive strength, split tensile strength, the flexural strength and the viability of the proposed GPC mix in the structural application.

2. MATERIALS

2.1 Fly Ash

The source of alumino-silicate was low-calcium (Class F) fly ash which was obtained in a thermal power plant. The fly ash was light grey in color having spherical particles that led to enhancement of workability. It contained silica and alumina in large quantities and hence could be geopolymerized. The sample of fly ash is shown in Fig.1.

Fig.1 Fly ash

2.2 Ground Granulated Blast Furnace Slag (GGBFS)

GGBFS was applied as a secondary binder to strengthen the early formation of strength. It also had high calcium oxide content that encouraged quick reaction and creation of calcium-alumino-silicate-hydrate (C-A-S-H) gel besides geopolymeric gel.

2.3 Alkaline Activator Solution

The alkaline activator was made up of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solutions. Following the preparation of 8 molar NaOH solution, sodium hydroxide pellets were first dissolved in distilled water. Sodium silicate solution was combined with the NaOH solution in a predetermined ratio and left to equilibrate and then used.

2.4 Aggregates

The fine aggregate used was locally available river sand that met Zone II. The nominal maximum size of the crushed granite coarse aggregate was 20 mm. At the time of mixing, both fine and coarse aggregates were in drier conditions of saturated surface.

2.5 Water

The alkaline solution was prepared and used using potable water and also to clean. The GPC mix was not supplemented with more water.

3. MIX PROPORTION AND METHODOLOGY

3.1 Mix Design

The GPC was aimed at obtaining M30 grade strength. The constituents of binder were fly ash and GGBFS in 60:40 proportion by mass. The ratio of alkaline activator to binder, sodium silicate to sodium hydroxide was selected after prior trials to have a good amount of workability and strength.

3.2 Mixing Procedure

Fly ash, GGBFS, fine aggregate and coarse aggregate were initially combined in a pan mixer to produce the dry materials. Alkaline activator solution was gradually added which was pre-prepared and the mixture was mixed until a homogeneous workable mix was attained.

3.3 Casting and Curing

Flexural strength (prisms), compressive strength (cubes), split tensile strength (cylinders) were cast on standard moulds using concrete specimens. The specimens were kept at ambient temperature after the process of casting. Demoulding was done after 24 hours, and ambient curing was done until the corresponding ages of testing.

4. EXPERIMENTAL PROGRAM

The compressive strength tests on cube specimens were carried out at 3, 7 and 28 days with respect to the relevant standards. A load was put on until failure and the highest load was taken. The determination of split tensile strength was done at 7 and 28 days in cylindrical specimen. The test was performed by compressing with diametral compressive load up to failure. The measurement of flexural strength was applied to the prism specimen on the two-point loading at 7 and 28 days. The failure load was used to compute the modulus of rupture.

5. DISCUSSION ON TEST RESULTS

5.1 Compressive Strength

Table 1 presents the compressive strength results of GPC with various proprotions of fly ash and GGBFS

Table 1. Compressive strength results of GPC

Mix ID	Compressive Strength (MPa)		
	3 DAYS	7 DAYS	28 DAYS
FA100	10.22	17.60	34.40
FA80G20	14.80	22.90	35.60
FA60G40	18.50	26.80	38.60
FA40G60	17.90	25.70	36.05
FA20G80	16.60	23.04	35.74

Fig.2 indicates that binder composition has a definite effect on the early-age and the long-term strength development in the compressive strength results of GPC with different proportions of fly ash-GGBFS. The FA100 mixture had the lowest level of strength at all ages; especially at 3 days, which means that under ambient curing, the geopolymerization rate of fly ash is slower when applied solely.

The replacement of the fly ash with GGBFS in small quantities enhanced the early-age strength remarkably as it was the case in FA80G20 and FA60G40 mixes because of the availability of calcium which increases the reaction kinetics. A balance between fly ash and GGBFS was best seen in the

FA60G40 mixture that had the highest 28-day compressive strength of 38.60 Mpa, which was greater than the target strength of M30. Even though higher GGBFS levels of mixes (FA40G60 and FA20G80) demonstrated good early strength, there was a slight drop in 28-day strength, maybe as a result of rapid setting and inability to develop geopolymer gels at older ages. Generally, the findings reveal that fly ash to GGBFS ratio of 60:40 reflects the most effective mixture of the concrete to accomplish improved mechanical performance and sustainable GPC when the material is subjected to ambient curing.

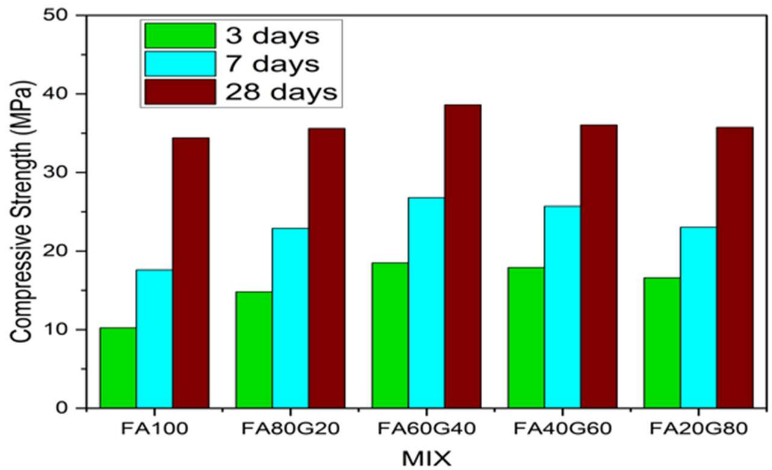

Fig.2. Compressive strength of different GPC mixes

5.2 Split Tensile Strength

Table 2 shows the split tensile strength data of GPC in various ratios of fly ash-GGBFS after 7 and 28 days under ambient curing.

Table 2. Split tensile strength results of GPC

Mix ID	Split Tensile Strength (MPa)	
	7 days	28 days
FA100	2.10	3.52
FA80G20	2.55	3.75
FA60G40	2.70	3.90
FA40G60	2.61	3.62
FA20G80	2.43	3.40

The split tensile strengths outcomes of GPC at various ratios of fly ash to GGBFS exhibit a steady rise between 7-28 days of all mixes which suggests continuous maturity of geopolymer matrix. FA100 mix had least tensile strength especially on 7 days basis because the fly ash is slower to react under ambient curing conditions as indicated in Fig.3. The GGBFS puzzle enhanced the tensile strength and most importantly; the FA60G40 mix had the highest split tensile strength of 28 days of 3.90 Mpa which shows how the calcium plays a positive role in improving the bond strength and crack resistance. Though mixes of higher GGBFS content (FA40G60 and FA20G80) demonstrated rather good early tensile performance, there was a slight loss of strength at 28 days, which indicated that excessive GGBFS can result into early formation of a matrix with minimal strength development in the long-term. In general, according to the results, the fly ash-GGBFS ratio of 60:40 is the optimum level to enhance tensile performance without compromising material. sustainability.

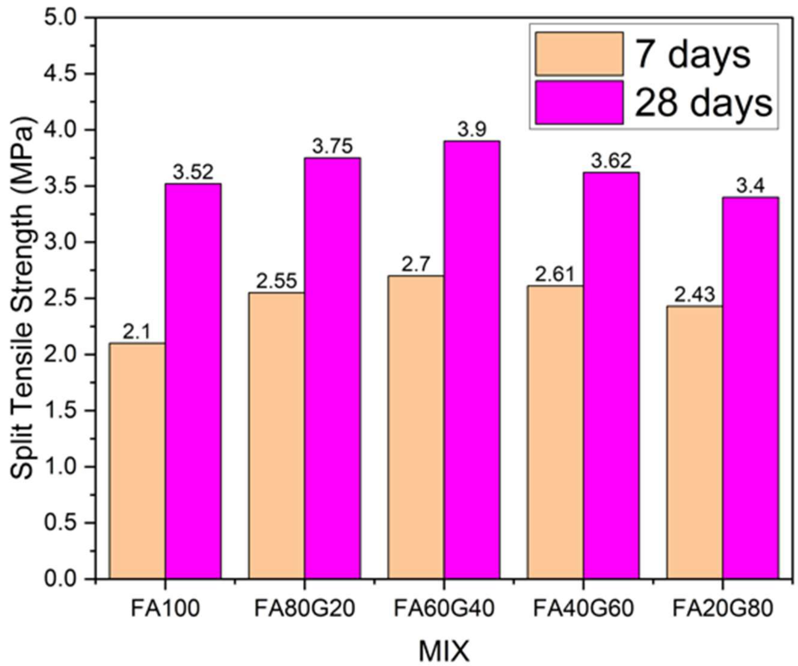

Fig.3. Split tensile strength for various GPC mixes

5.3 Flexural Strength

Table 3 presents the flexural strength results of GPC with varying fly ash–GGBFS ratios tested at 7 and 28 days under ambient curing conditions.

Table 3. Flexural strength results of GPC

Mix ID	Flexural Strength (MPa)	
	7 Days	28 Days
FA100	3.10	4.25

FA80G20	3.55	4.78
FA60G40	4.05	5.82
FA40G60	3.78	5.56
FA20G80	3.25	5.24

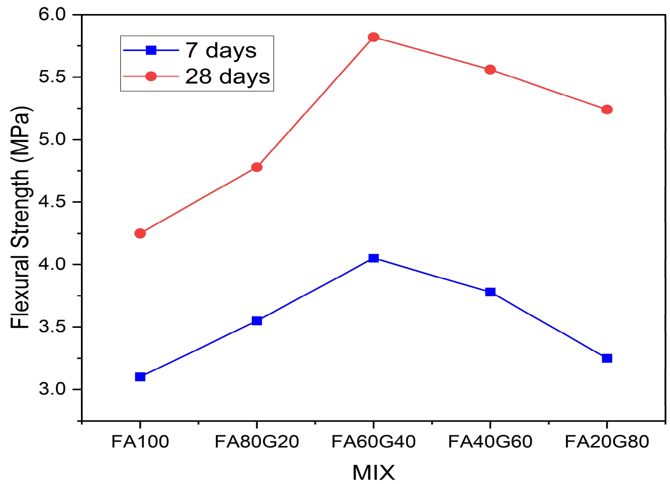

Fig.4. Flexural strength for various GPC mixes

A comparative strength flexural results of GPC with different ratios of fly ash-GGBFS indicates that there is an observable improvement in the flexural results with the addition of curing age to all mixes and this is associated with continuous progression of the geopolymer binder matrix as evident in Fig.4. It is possible to say that the FA100 mix had the lowest flexural strength at 7 and 28 days because its geopolymerization was slower and less robust when using a matrix without calcium. Replacement of fly ash with GGBFS in a partial manner enhanced flexural performance in a significant way as the FA60G40 mix had the highest 28-day flexural strength of 5.82 Mpa. This increase is linked to the increase in matrix densification and increase in interfacial bonding between aggregates and the geopolymer paste. Even though mixes with increased specifications of GGBFS (FA40G60 and FA20G80) demonstrated relatively good flexural strength, weakened slightly in comparison with FA60G40 after 28 days, potentially because early reactions caused minimal strength to be gained. Generally, the findings demonstrate that the ratio of 60: 40 fly ash-GGBFS is the most suitable ratio needed to achieve good flexural performance of GPC under ambient curing conditions.

6. CONCLUSIONS

According to the experimental study on M30 grade GPC with the addition of fly ash and GGBFS that are subjected to the 8 M alkaline solution and cured in ambient environment, the following conclusions can be drawn:

I. Mechanical performance of GPC in terms structure grade binders, which was prepared with fly ash-GGBFS, proved to be satisfactory, which attests to the suitability of the use of GPC in place of ordinary Portland cement.
II. Compressive, split tensile and flexural strengths were lowest in FA100 mix at any curing age, which suggested that the mix geopolymerized slower when fly ash was employed as the only binder under ambient conditions.
III. The use of fly ash GGBFS in its partial place allowed improving the early-age and 28-day strengths by a significant margin because of the availability of calcium, which influenced the reaction kinetics and increased the densification of the matrix.
IV. The FA60G40 mix had the best 28-day compressive strength (38.60 MPa), split tensile strength (3.90 MPa), and flexural strength (5.82 Mpa), which were more than the target M30 requirements and suggested an optimal fly ash-GGBFS ratio.
V. Higher-GGBFS content (FA40G60 and FA20G80) mixes also demonstrated better early-age strength, but with a slight decrease in geopolymer development of 28 days, implying that too much GGBFS can be detrimental to long-term development of geopolymers.
VI. The addition of an 8 M of alkaline activator was also observed to be sufficient in dissolving the alumino-silicate materials effectively leading to a stable and well bonded geopolymer matrix at ambient curing conditions.
VII. In general, a fly ash-GGBFS ratio of 60:40 will be the most beneficial to balance between the strength performance and sustainability and will be considered a viable and eco-friendly alternative to the standard OPC-based M30 concrete.

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