CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2025; 35 (4): 0150-0163
DOI: 10.59440/ceer/205940
*Original Research Article*

# INVESTIGATING THE RHEOLOGY AND STRENGTH OF SELF-COMPACTING GEOPOLYMER CONCRETE USING BLAST FURNACE SLAG AND FLYASH

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A b s t r a c t

Building energy requirements have risen drastically in the modern era, partly because of expanding populations and broadened human lifestyles. Greater energy demand, depletion of fossil resources, and environmental concerns constitute crucial motivating factors in building enticing and sustainable infrastructure. In the current situation, environmental management is an urgent problem that has to be highlighted. This article covers an experimental study that evaluates the use of industrial waste as a substitute for cement in self-compacting geopolymer concrete. To serve as a binder in geopolymer concrete with the further advantage of self-compaction, industrial residues such as blast furnace slag from the metals sector and flyash from thermal plants are researched for their fresh and hardened characteristics tapping into geo-polymerization. An alkaline solution can be generated by maintaining a 2.5 ratio of sodium silicate to sodium hydroxide at 12M NaOH. Eleven mixes together with varied proportions of granulated ground blast furnace slag and flyash have been assessed for workability, strength with durability. The results of experimental work indicate that the development of self-compacting geopolymer concrete using a binder made exclusively of granulated ground BFS an industrial waste 12G100F0 is an effective combination that provides sufficient workability, strength, and durability.

Keywords: blast furnace slag, alkaline solution, geo-polymerization, flyash, self-compacting geopolymer concrete

## 1. INTRODUCTION

As the nation's building techniques move forward, cementitious materials are significantly deployed as constructing resources. The greenhouse effect is heavily impacted by cementitious concrete. A staggering thirty percent of global carbon dioxide emissions are linked to concrete manufacture [1]. In construction projects, the microscopic particle size of the cement system demonstrates an impressive sticky binding ability. However, an important amount of carbon dioxide ($CO_2$) is released all

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throughout the cement manufacturing process [2]. The grinding of minerals, burning of fossil fuels, and the preparation of materials in the kiln chamber all yield $CO_2$ emissions that adversely affect the environment. Furthermore, the cement sector jointly contributes considerable $CO_2$ emissions [3,4]. The emission which causes global warming has a tremendous detrimental impact on the environment. Ordinary Portland cement (OPC) adds substantially to the earth's $CO_2$ emissions, comprising around 8% of the overall human $CO_2$ output. The process of production of cement contains gases hazardous to the biosphere [5,6]. The main causes of gaseous emissions are thought to be the heating and combustion of raw materials and the calcination process. Escalating growth in industrialisation and human activities have contributed to the emission of numerous contaminants into the environment [7, 8].

The adoption of Geopolymer concrete (GPC) in the building sector provides a sustainable method for lowering $CO_2$ emissions and utilisation of energy during manufacturing and implementation [9]. Recycling and reusing industrial waste have been recognised as a viable approach for environmental management: reducing consumption of energy, calming landfill burden, and mitigating environmental damage [10]. The source materials to feed geopolymer binders, mostly made up of aluminosilicates, originate primarily coming from industrial waste products. These consist of metakaolin (MK), flyash (FA), ground granulated blast furnace slag (BFS), red mud (RM), iron ore tailings (IOT), rice husk ash (RHA), and ferrochrome ash (FCA) [11]. Geopolymer binders are presently employed for multiple infrastructure projects worldwide, prompted by broadened discoveries and expanding manufacturing techniques [12,13]. Geopolymers are revolutionary inorganic substances that exhibit a chemical structure akin to zeolites, or crystalline aluminosilicates. However, they retain an amorphous, ceramic-like underlying structure [14]. A polymeric Si-O-Al chain, referred to as poly-sialates, develops by the mixture of alkaline solutions with aluminosilicate source materials, giving rise to a three-dimensional network of silicon and aluminium interconnected by oxygen [15,16]. The alkaline solutions are composed of sodium and/or potassium hydroxides and/or silicates. Polycondensation emerges when alkaline solutions interact with the source materials during mixing, triggering the breakdown of silicon and aluminium ions within the system [17]. The kind and concentration of chemical oxides in the source materials greatly impact the scale of the geopolymer reaction. The amount of CaO, MgO, and $Fe_2O_3$ in source materials affects geo-polymerization on top of $SiO_2$ and $Al_2O_3$ [18, 19].

FA and BFS are regarded as the most dependable raw materials enabling the manufacturing of geopolymer binders. The reason for the higher utilisation rate of SiO2 and Al2O3 in geopolymer binder production lies in the presence of them in both FA and BFS, jointly with their worldwide availability and acceptable physical and chemical properties [20]. The prolonged setting process of FA, its insufficient early age strength, and the demand for higher temperatures in order for reaching strength are prominent downsides [21]. However, because of the significant amount of CaO and MgO in BFS, which improve matrix stability while also leading to an overall decrease in curing temperature, using it is highly advisable. BFS is an outcome of the steel production method. Melting slag is generated by combustion of iron ore, limestone and coke at temperatures that vary between 1400 to 1500 degrees Celsius in a blast furnace [22]. The iron particles in the molten slag are then quenched using water, and the resulting material is then crushed to the desired fineness to generate BFS. It consists many mineral constituents, including calcium oxides, aluminates, and silicates [23,24]. The 19th century defined the initial use of BFS as a possible substitute to cement in the development of bricks, binders, and concrete components [25, 26]. One ton of Blast furnace slag generate only 70 kg of $CO_2$ which is just 7% of the $CO_2$ emission due to one ton production of cement. Therefore, it will aim at controlling $CO_2$ emissions and handle recyclables for bettering the environment. Afterwards, studies focused on the alkali activation of BFS as a successor to the standard cement-based binder system [27]. BFS presents an appealing option for integration into blended cement-based and geopolymer binder systems because of its significant level of calcium, silica, and alumina in an amorphous state. Heat is vital for the geopolymer binder reaction process. The beneficial effect of heat on the growth of strength is important. However, the precast industries stay among the only users of geopolymer binders, mostly since their demand for heat or raised curing conditions [28, 29, 30]. Heat curing quickens the advancement of strength; however, it simultaneously raises the cost of manufacturing. This emphasises the importance for ambient curing in order to enable more expansive utilisation of geopolymer binders. A number of professionals created geopolymer binders at room temperature making use of calcium-rich alternatives that include BFS [31]. However, enhancing the benefit of geopolymer concrete with self compacting behaviour is an advantage that scientist are looking for. Hence, in present study, the gap of exploring self compacting geopolymer concrete (SCGPC) has been tried to be filled using blend of BFS and FA as binder under ambient curing conditions

## 2. EXPERIMENTALROGRAM

### 2.1. Blast Furnace Slag

BFS is a cementitious material mainly employed in concrete production adhering to its breakdown to an appropriate size. The material itself is a by-product that results from the procedures performed within iron-making blast furnaces [32]. Following extracting iron from the iron ore, the remaining components are incorporated to generate slag, which floats just above the iron. Promptly quenching this liquid molten slag in an enormous amount of water is necessary for its use as a binder. This slag is periodically tapped out [33].The quenching process increases the cement-like characteristics and ends up in granules that have similarities to coarse sand. The "granulated" slag is then crushed into a fine powder after undertaking a drying stage [34]. Table 1 details the chemical composition of ground granulated BFS, whereas Table 2 outlines its physical characteristics.

Table 1. Chemical Composition of ground BFS

| Sample | $SiO_2$ | $Al_2O_3$ | CaO | $Fe_2O_3$ | MgO | $SO_3$ | MnO | LOI |
|---|---|---|---|---|---|---|---|---|
| GGBFS | 33.89 | 16.99 | 36.97 | 0.708 | 7.79 | 0.5 | 0.199 | 0.489 |

Table 2. Physical Properties of ground BFS

| Sample | Specific Gravity | Fineness modulus | Colour | Bulk Density ($kg/m^3$) | Surface Area ($m^2/kg$) | Particle Size (micron) |
|---|---|---|---|---|---|---|
| GGBFS | 2.85 | 3.75 | Light Grey | 1200 | 450 | Avg. 45 |

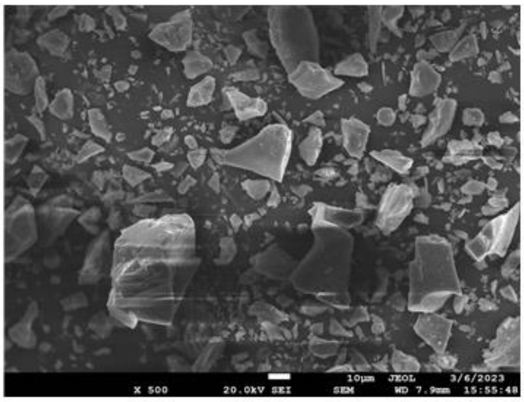


Fig. 1. SEM image of BFS

## 2.2. Significance of CaO present in BFS

The process of enhancing iron ore generates slag, that is subsequently quenched to generate granulated ground BFS as a by-product [35]. Granulated ground BFS can be produced via the grinding of BFS, which predominantly comprises sand-sized particles, in a ball mill to produce smaller sizes [36]. Furthermore, it is essential to understand that the extent of fineness or grinding strongly impacts the responsiveness of BFS. Excessive calcium presence shortens setting time, increases shrinkage, triggers microcrack growth, and results in expansion [37]. Researchers constructed geopolymer concrete applying 100% BFS, with an 8 molar sodium hydroxide (NaOH) solution and sodium silicate ($Na_2SiO_3$) in a proportion of 1:2.5 [38].

## 2.3. Coarse Aggregate

In the present investigation, crushed stones having a diameter of 12.5 mm have been used for the production of SGC. Experiments are conducted in accordance with Indian Standard Codes to figure out the water absorption and specific gravity of the 12.5 mm-sized coarse aggregate. Table 3 lists the characteristics of coarse aggregates.

Table 3. Characteristics of Coarse Aggregate

| Material Properties | Specific Gravity | Fineness Modulus | Bulk Density kg /$m^3$ | Type | Grade | Water absorption |
|---|---|---|---|---|---|---|
| Values | 2.671 | 6.146 | 1568 | Crushed stones | 12.5mm | 0.60% |

## 2.4. Alkali Activator Solution

Sodium hydroxide and sodium silicate were blended together to generate an alkaline solution for the purpose of this study. Both of these substances are currently easily accessible in the market for many different industrial uses. Sodium silicate helps the more thorough breakdown of the binder's components [39]. Industrial grades of both alkalis have been obtained from regional suppliers. The ratio of silicate oxide to sodium oxide in the Na-silicate aqueous solution is 2:1 [40]. Table 4 lists the properties of sodium silicate.

Table 4. Physical and Chemical Properties of Sodium Silicate

| Chemical Formula | $Na_2O$ | $SiO_2$ | $H_2O$ | Appearance | Molecular Weight | Boiling Point | Specific Gravity | Colour |
|---|---|---|---|---|---|---|---|---|
| $Na_2SiO_3$ | 14.73% | 29.75% | 55.52% | Liquid (Gel) | 184.04 | 102ºC | 1.39 | colour-less |

Fig. 2. Sodium Hydroxide

Sodium hydroxide pellets must be mixed in water to achieve a certain concentration before the solution develops. Variations could occur in the molar content of the sodium hydroxide solution. Regarding the concentration of the sodium hydroxide solution, 400 grams of solid sodium hydroxide could be found in the mixture with a molarity of 10 moles per litre of water [41]. Due to its molecular weight of 40, one mole of NaOH has a mass of 40 grams. Every litre of water would contain 400 grams of NaOH in a 10 M NaOH solution. A total of 314 grams of solid sodium hydroxide in per kilogramme of sodium hydroxide solution.

Fig. 2. Sodium Silicate solution

### 2.5. Water

A recently developed line of superplasticizers, referred to as Procrete SCC, formulated from modified poly-carboxylic ether, has been employed in the present research (Figure 4). Role of super-plasticizer is to improve the workability behaviour of concrete mix.

### 2.6. Super-plasticizer

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## 3. METHODOLOGY

### 3.1 Alkaline activator solution preparation

The polymerisation of aluminosilicates is reliant upon alkaline activators [42-43]. The total amount of sodium hydroxide in the alkaline solution is conditional by its concentration (i.e., molarity). As a result, an alkaline activator solution can be created through the combination of NaOH and Na2SiO3 solutions [44]. The NaOH solution is added over time while maintaining thorough mixing to generate a uniform mixture. A substantial amount of heat flows out during the chemical process of sodium hydroxide [45]. A Sodium hydroxide solution is prepared 24 hour before to the casting of the specimens.

Table 5. Composition of Self compacting GPC per cubic meter of concrete

| Mix | Molarity (M) | BFS (kg/m$^3$) | flyash (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | NaOH (kg/m$^3$) | $Na_2SiO_3$ (kg/m$^3$) | Super plasticizer (%) |
|---|---|---|---|---|---|---|---|---|
| 12B100F0 | 12 | 440 | 0 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B85F15 | 12 | 374 | 220 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B75F25 | 12 | 330 | 110 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B65F35 | 12 | 286 | 154 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B55F45 | 12 | 242 | 198 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B50F50 | 12 | 220 | 220 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B45F55 | 12 | 198 | 242 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B35F65 | 12 | 154 | 286 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B25F75 | 12 | 110 | 330 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B15F85 | 12 | 220 | 374 | 920 | 840 | 56.57 | 141.43 | 5 |
| 12B0F100 | 12 | 0 | 440 | 920 | 840 | 56.57 | 141.43 | 5 |

Table (5) shows the composition of various constituents as per mix design. This study explores replacing cement with a blend of Ground Granulated Blast Furnace Slag (BFS) and flyash (FA) in varying proportions, ultimately eliminating the need for cement. The mixture is labelled as 12BXFY, where "12" represents molarity, "B" denotes Ground Granulated BFS, and "F" signifies flyash, with "X" and "Y" indicating the respective replacement percentages.

## 4. FRESH AND MECHANICAL PROPERTIES

### 4.1. Fresh Properties

The laboratory test studied the workability of self-consolidating GPC, utilising Ground granulated BFS and flyash with a goal to measure its flowability, viscosity, and ease of laying without mechanical vibration.

(a) (b) (c)

Fig. 3. Workability test of developed SCGPC (a) slump flow test (b) L-Box test (c)J-Ring test

Table 6. Fresh Properties of BFS and flyash based SCGPC

| Mix | Slump-flow (mm) | $T_{50cm}$ Slump flow (sec) | V-funnel flow time (sec) | V-funnel $T_{5min}$ time (sec) | L-box ($H_2/H_1$) | J-Ring test (mm) |
|---|---|---|---|---|---|---|
| **12B100F0** | 698 | 4.5 | 12 | 14 | 0.90 | 6 |
| **12B85F15** | 700 | 4.5 | 12 | 14 | 0.90 | 6 |
| **12B75F25** | 700 | 4.5 | 11.5 | 13.2 | 0.91 | 6 |
| **12B65F35** | 702 | 4.3 | 1.5 | 13 | 0.92 | 6 |
| **12B55F45** | 703 | 4.3 | 11.5 | 13 | 0.92 | 6 |
| **12B50F50** | 703 | 4.0 | 11.5 | 13 | 0.92 | 6 |
| **12B45F55** | 7.5 | 3.8 | 11 | 12 | 0.93 | 5 |
| **12B35F65** | 706 | 3.8 | 11 | 12 | 0.93 | 5 |
| **12B25F75** | 706 | 3.6 | 11 | 11.5 | 0.94 | 5 |
| **12B15F85** | 708 | 3.6 | 10 | 11 | 0.94 | 5 |
| **12B0F100** | 710 | 3.5 | 10 | 11 | 0.95 | 5 |

Table 6 illustrates that the workability performance of all mixes developed with BFS and FA. All the mixes tend to satisfy the self compacting behaviour of developed SCGPC. All results used to evaluate flowability, passing ability, and segregation resistance indicate adequate performance for all mixes. In accordance with Table 7, the most effective strength of 44.28MPa after 28 days ambient curing is exhibited by 12B100F0; hence, a 12 Molar concentration of NaOH was chosen for the proposed binder of flyash and BFS.

## 4.2. Test for hardened properties of SCGPC

For evaluation of the variability of strength parameters, certain strengthened attributes were evaluated. These include compressive strength, split tensile strength, and flexural strength. Specimens of cubes, cylinders, and beams with dimensions agreeing to IS 516 (1959) [46] were employed. The specimens' strength had been assessed after seven, fourteen, and twenty-eight days in order to determine the variance in strength obtained.

Table 7. Hardened Properties of SCGPC

| Mix | "Compressive strength" (MPa) | | | "Split Tensile strength" (MPa) | | | "Flexural strength" (MPa) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7Days | 21Days | 28Days | 7Days | 21Days | 28Days | 7Days | 21Days | 28Days |
| 12B100F0 | 38.45 | 41.63 | 44.28 | 2.71 | 2.94 | 3.09 | 2.95 | 3.05 | 3.28 |
| 12B85F15 | 37.51 | 39.4 | 41.2 | 2.63 | 2.85 | 3.01 | 2.91 | 3.03 | 3.19 |
| 12B75F25 | 34.69 | 37.42 | 39.27 | 2.37 | 2.62 | 2.77 | 2.82 | 2.89 | 3 |
| 12B65F35 | 32.8 | 34.32 | 37.6 | 2.35 | 2.59 | 2.59 | 2.43 | 2.78 | 2.94 |
| 12B55F45 | 30.7 | 33.1 | 36.15 | 2.32 | 2.48 | 2.46 | 2.4 | 2.72 | 2.91 |
| 12B50F50 | 29.32 | 32.88 | 35.95 | 2.3 | 2.38 | 2.45 | 2.54 | 2.67 | 2.8 |
| 12B45F55 | 28.3 | 31.20 | 34.23 | 2.1 | 2.32 | 2.34 | 2.41 | 2.58 | 2.75 |
| 12B35F65 | 26.4 | 30.25 | 30.15 | 2.08 | 2.29 | 2.31 | 2.37 | 2.4 | 2.64 |
| 12B25F75 | 24.25 | 26.52 | 28.81 | 2.06 | 2.19 | 2.27 | 2.28 | 2.41 | 2.52 |
| 12B15F85 | 22.42 | 21.56 | 25.63 | 2.02 | 2.03 | 1.9 | 2.16 | 2.15 | 2.34 |
| 12B0F100 | 17.95 | 19.39 | 22.32 | 1.52 | 1.57 | 1.6 | 1.85 | 1.92 | 2 |

As indicated in Table 7, the ideal mechanical strength are demonstrated by mix 12B100F0. It can be observed from Table 6 that 12B100F0 has satisfactorily passed the flowability, passing ability and segregation resistance conducted as per EFNARC (2005) [22] Also as per Table 7 the best strength results for compressive, split tensile and flexure are observed after 7-days, 21-days and 28-days of curing for 12B100F0. Therefore, a 12M solution of NaOH, employing 100% BFS as a binder and a sodium silicate to NaOH ratio of 2.5, has been recommended as optimized mix designated as 12B100F0. It has been observed [6] that with 2% superplasticizer the highest mechanical strength has been observed with blend of 50% BFS and 50% Class F flyash as binder with 12 M NaOH solution and ratio of $Na_2Si0_3$ to NaOH as 2.5.


(a) (b) (c)

Fig. 4. Mechanical Strength test of SCGPC (a) Compressive strength (b) Split tensile strength (c) flexural strength

### 4.3. Water permeability test

The water permeability test on 28-day cured concrete specimens for the improved concrete mix 12B100F0 is carried out in compliance with BS EN 12390-8 [47] and DIN 1048 Part 5 [48].The concrete has to be cured and thoroughly cleaned (sides smoothed and surface imperfections minimised) in advance of testing. A water pressure, commonly between 0.5 and 1 MPa, is forced on the upper surface of the concrete specimen using a water pump. The upper surface of the specimen is subjected to water pressure, whereas the sides and bottom are sealed to avoid water from seeping through unexpected ways. The steady water pressure is maintained for 72 hours. After three days, the samples are taken out from the testing device, separated vertically, and the maximum depth of water penetration is determined [49]. The measurement was recorded at 20mm, which is appropriate. The average dimension is often a 150 mm cube. Observations are listed in Table 8.

### 4.4. RCPT test

Rapid Chloride Penetration Test (RCPT) evaluates chloride penetration in the concrete mix as per ASTM C1202. Cylindrical specimens (100 mm diameter, 200 mm depth) of listed mix in Table 8 are prepared and sliced into 50 mm samples. These are vacuum saturated to replace air voids with water, then placed in the RCPT apparatus, sealed with silicone, and filled with NaOH (0.3M) in the positive diode and NaCl (3%) in the negative diode. A 60V DC current is applied, and the current (mA) is recorded every 30 minutes for 6 hours. Average current reading are shown in Table 8.

Table 8. Water Permeability test for SCGPC

| Mix ID | Depth of water permeability (mm) | RCPT (I avg) |
|---|---|---|
| 12B100F0 | 20 | 3222 |
| 12B85F15 | 22.1 | 3257 |
| 12B75F25 | 22.4 | 3486 |
| 12B65F35 | 23.2 | 3492 |
| 12B55F45 | 24 | 3593 |
| 12B50F50 | 25.2 | 3628 |
| 12B45F55 | 26 | 3780 |
| 12B35F65 | 25.8 | 3910 |
| 12B25F75 | 26 | 3920 |
| 12B15F85 | 26.5 | 3933 |
| 12B0F100 | 27.2 | 3975 |


(a) (b)

Fig. 5. Durability test (a) Water permeability test (b) RCPT test for developed SCGPC

## 4.5. SEM analysis

SEM aids the analysis of the matrix and the distribution of flyash, Ground Granulated BFS, and other particles within SCGPC. It provides detailed electronic images of the geopolymer matrix for assessing the growth and adhesion of the binder to the aggregates [50]. The SEM image illustrates the thick matrix framework of the 12B100F0 blend. Figure 8 depicts the advancement of homogeneous alumino-silica matrices characterised by decreased pores.

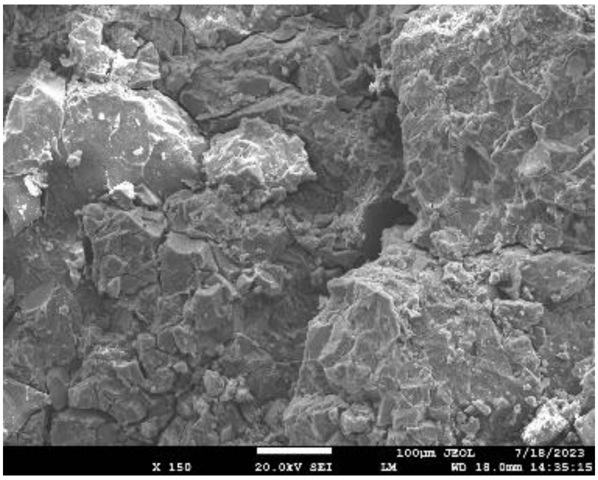


Fig. 6. SEM image of 12B100F0 after 28 days of ambient curing

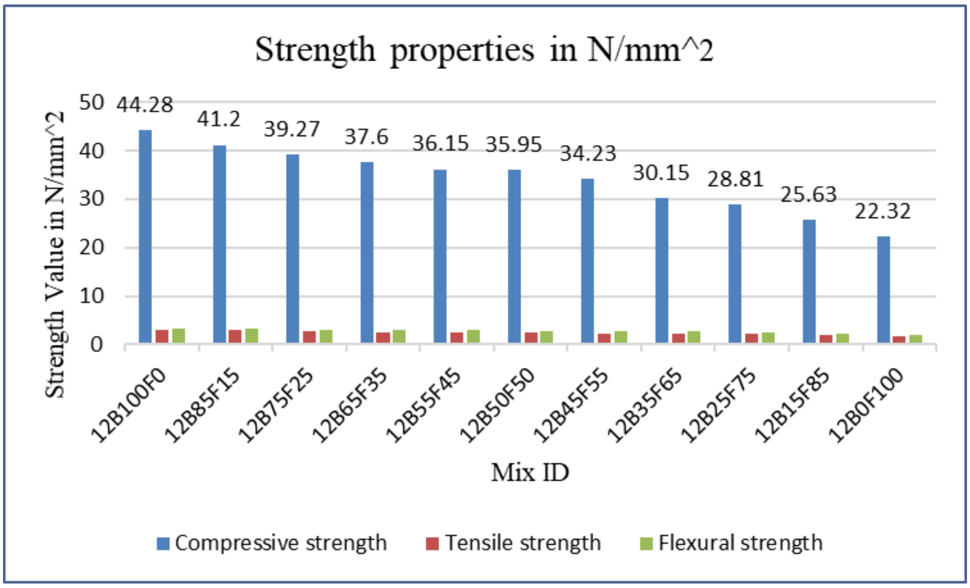


Fig. 9. Strength properties of various mix after 28 days of ambient curing

## 5. DISCUSSION OF RESULTS

The observations regarding the self compacting behaviour of developed geopolymer concrete mixes shown in Table 6 indicate that the addition of flyash improves workability due to its spherical particle shape, while granulated BFS. Similar behaviour has been observed by researchers while using the blend of GGBS and flyash [6]. while granulated BFS, being amorphous, enhances reactivity and strength development, refer Fig. 9. It has been observed that 12B100F0 mix demonstrates highest compressive strength, split tensile strength and flexural strength after 28 days of ambient curing. Mechanical strength development is an important criterion in recommendation of a concrete mix as optimized mix. Regarding durability, the water permeability of the 12B100F0 mix is acceptable; however, replacing flyash at 50% or higher percentage results in excessive permeability (>25mm), which is undesirable. Despite all mixes falling within the permissible range in the RCPT test, 12B100F0 is recommended as the optimal blend based on its balanced workability, strength, and durability. Scanning electron microstructural analysis further supports the selection of 12B100F0, revealing a compact matrix, homogeneous mix, and reduced porosity, contributing to enhanced strength and durability.

## 6. CONCLUSIONS

It can be concluded from the experimental results that an entire 100% supplementation of cement with granulated ground blast furnace slag as a binder is conceivable to produce self compacting geopolymer concrete. In the study blend of BFS and flyash has been used as a binder fixing the molarity of NaOH at 12 and ratio of sodium silicate to sodium Hydroxide as 2.5 with 5% superplasticizer at ambient curing. In all 11 mixes were tested with ground granulated BFS and flyash as (100/0, 85/15, 75/25, 65/35,55/45, 50/50, 45/55, 35/65, 25/75, 15/85, 0/100). Satisfactory workability behaviour has been observed with highest mechanical strength and satisfactory durability behaviour for 12G100F0. Also, the durability behaviour studied through RCPT for Chloride penetration and water permeability has been found to be satisfactory. To further justify the observations, SEM images strengthened the observed data with dense matrix for G100F0.

Hence, SCGPC accomplished with BFS in grounded form can serve as a successful tool for a sustainable environment. Though, the difficulties of qualified manpower and the expense of alkaline activator solutions are requirements for SCGPC. 100% replacement of cement with BFS, which is a industrial waste can make a significantly positive effect on environment by controlling CO2 emissions and managing the solid waste as well without compromising the technical requirements of self compacting concrete.

## REFERENCES


1. Deng, Li et al. 2019. Assessing the life cycle $CO_2$ emissions of reinforced concrete structures: Four cases from China. Journal of cleaner production, 210, pp.1496-1506.
2. Shi, C et al. 2011. New cements for the 21st century: The pursuit of an alternative to Portland cement. Cement and concrete research, 41(7), pp.750-763.
3. Zhang, J et al. 2014. Analysis of $CO_2$ emission for the cement manufacturing with alternative raw materials: a LCA-based framework. Energy Procedia, 61, pp.2541-2545.
4. Akbar, A et al. 2021. Sugarcane bagasse ash-based engineered geopolymer mortar incorporating propylene fibers. Journal of Building Engineering, 33, p.101492.
5. Valderrama, C et al. 2012. Implementation of best available techniques in cement manufacturing: a life-cycle assessment study. Journal of Cleaner Production, 25, pp.60-67.
6. Ramineni, K et al. 2018, April. Performance studies on self-compacting geopolymer concrete at ambient curing condition. In International Congress on Polymers in Concrete (pp. 501-508). Cham: Springer International Publishing.
7. Embong, R et al. Strength and microstructural properties of fly ash based geopolymer concrete containing high-calcium and water-absorptive aggregate, Journal of cleaner production , vol. 112, pp. 816–822, Jan. 2016, doi: 10.1016/J.JCLEPRO.2015.06.058.
8. Chaturvedy, GK et al. 2024. Incorporating multi-walled carbon nanotubes in rubberized concrete: impact on physical, mechanical, and fire resistance properties. Fullerenes, Nanotubes and Carbon Nanostructures, 32(12), 1121–1134. https:// doi.org/10.1080/1536383X.2024.2375597
9. Kansotiya M Journal of cleaner production 2024. Influence of nano silica and crumb rubber on the physical and durability characteristics of concrete. Multiscale and Multidiscip. Model. Exp. and Des. 7, 2877–2892.
10. Rais, MS et al. An experimental and analytical investigation into age-dependent strength of fly ash mortar at elevated temperature, Construction and Building Material, vol. 222, pp. 300–311, Oct. 2019.
11. Okoye, FN 2017. Geopolymer binder: A veritable alternative to Portland cement. Materials Today: Proceedings, 4(4), pp.5599-5604.
12. Castel, A et al. 2010. Bond and cracking properties of self-consolidating concrete, Constr Build Mater, vol. 24, no. 7, pp. 1222–1231.
13. Chaturvedy, GK et al. 2023. Analyzing the behavior of graphene oxide on high-strength rubberized concrete properties using different optimization techniques, Diamond and Related Materials, Volume 140, 110485.
14. Rożek, P et al. 2019. Geopolymer-zeolite composites: A review, Journal of Cleaner Production, vol. 230, pp. 557–579.
15. Fernández-Jiménez, A et al. 2005. Microstructure development of alkali-activated fly ash cement: a descriptive model. Cement and concrete research, 35(6), pp.1204-1209.

16. Palomo, A et al. 1999. Alkali-activated fly ashes: A cement for the future. Cement and concrete research, 29(8), pp.1323-1329.
17. Kovalchuk, G et al. 2007. Alkali-activated fly ash: Effect of thermal curing conditions on mechanical and microstructural development–Part II. Fuel, 86(3), pp.315-322.
18. Turner, LK and Collins, FG 2013. Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete. Construction and building materials, 43, pp.125-130.
19. Saini, R et al. 2024. Examining the effects of nano iron oxide on physical and mechanical characteristics of rubberized concrete. Innovative Infrastructure Solutions, 9(6), p.180.
20. Jagadesh, P et al. 2022. Effect of nano titanium di oxide on mechanical properties of fly ash and ground granulated blast furnace slag based geopolymer concrete. Journal of building engineering, 61, p.105235.
21. Amran, M et al. 2021. Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-term durability properties. Construction and Building Materials, 270, p.121857.
22. Yedukondalu, C and Sashidhar, C 2019. Mechanical Properties Of Self Compacting Geopolymer Concrete At Elevated Temperature. Int. J. Tech. Innov. Mod. Eng. Sci., 5.
23. Corinaldesi, V et al. 2010. Characterization of marble powder for its use in mortar and concrete. Construction and building materials, 24(1), pp.113-117.
24. Uygunoğlu, T et al. 2014. Use of waste marble and recycled aggregates in self-compacting concrete for environmental sustainability. Journal of cleaner production, 84, pp.691-700.
25. Ergün, A 2011. Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete. Construction and building materials, 25(2), pp.806-812.
26. Kuoribo, E and Mahmoud, H 2022. Utilisation of waste marble dust in concrete production: A scientometric review and future research directions. Journal of Cleaner Production, 374, p.133872.
27. Kou, SC and Poon, CS 2009. Properties of concrete prepared with crushed fine stone, furnace bottom ash and fine recycled aggregate as fine aggregates. Construction and Building Materials, 23(8), pp.2877-2886.
28. Dobiszewska, M et al. 2023. Utilization of rock dust as cement replacement in cement composites: An alternative approach to sustainable mortar and concrete productions. Journal of Building Engineering, 69, p.106180.
29. "Specification and Guidelines for Self-Compacting Concrete," 2002, Accessed: Oct. 14, 2024. [Online]. Available: www.efnarc.org
30. Donza, H et al. 2002. High-strength concrete with different fine aggregate. Cement and Concrete research, 32(11), pp.1755-1761.
31. Reed, M et al. 2014. Fibre-reinforced geopolymer concrete with ambient curing for in situ applications. Journal of materials science, 49(12), pp.4297-4304.
32. Yuksel, I 2018. Blast-furnace slag. In Waste and supplementary cementitious materials in concrete (pp. 361-415). Woodhead Publishing.
33. Li, G and Zhao, X 2003. Properties of concrete incorporating fly ash and ground granulated blast-furnace slag. Cement and concrete composites, 25(3), pp.293-299.
34. Özbay, E et al. 2016. Utilization and efficiency of ground granulated blast furnace slag on concrete properties–A review. Construction and Building Materials, 105, pp.423-434.
35. Bellmann, F and Stark, J 2009. Activation of blast furnace slag by a new method. Cement and Concrete Research, 39(8), pp.644-650.
36. Monosi, S et al. 2016. Electric arc furnace slag as natural aggregate replacement in concrete production. Cement and concrete composites, 66, pp.66-72.

37. Chindaprasirt, P et al. 2018. Effect of calcium-rich compounds on setting time and strength development of alkali-activated fly ash cured at ambient temperature. Case Studies in Construction Materials, 9, p.e00198.
38. Youssef, P et al. 2024. Characterization of geopolymer composites for 3D printing: a microstructure approach. Innovative Infrastructure Solutions, 9(5), p.157.
39. Rajan, HS and Kathirvel, P 2021. Sustainable development of geopolymer binder using sodium silicate synthesized from agricultural waste. Journal of Cleaner Production, 286, p.124959.
40. Asif, A et al. 2015, January. The effect of Si/Al ratio and sodium silicate on the mechanical properties of fly ash based geopolymer for coating. In Materials Science Forum (Vol. 803, pp. 355-361). Trans Tech Publications Ltd.
41. Phoo-Ngernkham, T et al. 2017. Effect of sodium hydroxide and sodium silicate solutions on strengths of alkali activated high calcium fly ash containing Portland cement. KSCE Journal of Civil Engineering, 21(6), pp.2202-2210.
42. Luke, O and Allistair, W and Bryan, M 2018. Preliminary Mix Design Procedure for Alkali Activated Cement Mortars Based on Metakaolin and Industrial Waste Products Activated With Potasium Silicate Proceeding of the 42nd International Conference on Advanced Ceramics and Composites.
43. Ahmed, H U et al. 2021. Compressive strength of sustainable geopolymer concrete composites: a state-of-the-art review. Sustainability, 13(24), p.13502.
44. Phoo-ngernkham, T et al. 2015. Effects of sodium hydroxide and sodium silicate solutions on compressive and shear bond strengths of FA–GBFS geopolymer. Construction and Building Materials, 91, pp.1-8.
45. Ebid, AM et al. 2023. Heat and mass transfer in different concrete structures: a study of self-compacting concrete and geopolymer concrete. International Journal of Low-Carbon Technologies, 18, pp.404-411.
46. Bereau of Indian Standards, “IS 516 (1959): Method of Tests for Strength of Concrete”.
47. EFNARC-2005 “Specification and Guidelines for Self-Compacting Concrete.” 2005. www.efnarc.org.Part 8, Depth of penetration of water under pressure,” p. 7, 2009.
48. BS EN 12390-8 [21] (DIN 1048 [22]).” Accessed: Oct. 16, 2024. [Online]. Available: https://www.scribd.com/document/418694693/330590102-DIN1048-Part-5-pdf
49. Jindal, BB et al. 2020. Effects of ultra fine slag as mineral admixture on the compressive strength, water absorption and permeability of rice husk ash based geopolymer concrete. Materials Today: Proceedings, 32, pp.871-877.
50. Zhao, K and Wang, Y 2022. Improvements on the use of GPC to measure large-size microstructures in aged asphalt binders. International Journal of Pavement Engineering, 23(7), pp.2309-2319.