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RESEARCH ARTICLE

A Review on Mechanical Properties and Sorptivity Coefficient of GGBFS and Fly Ash Based Geo-Polymer Concrete

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Abstract

Objectives: To study strength parameters and sorptivity coefficient of GGBFS and fly ash based M20, M40 geo-polymer concrete. **Methods:** Trials were carried out to compare mechanical properties and the sorptivity coefficient for M20, M40 grade of normal concrete (NC) with M20, M40 grade of geo-polymer concrete (GPC), in accordance with the design mix of IS 10262-2019. Sodium hydroxide and sodium silicate were chosen as alkaline solutions with a ratio of 1:2.1 and a molarity of 8M. A 50:50 binder material ratio (fly ash and GGBFS) is used in geo-polymer concrete by replacing the cement. A test for 7, 28, 56, and 90 days were carried out for compression, split tensile and flexure strength, followed by a 28-day test for sorptivity coefficient. **Findings:** GPC with molarity 8M, with a binder ratio of 0.23 for M40, and 0.29 for M20 GPC cured at ambient temperature, exhibited 14.19% higher strength for M40 grade and 43.81% higher strength for M20 grade in comparison with normal concrete. The water absorption rate of GPC with GGBFS and fly ash was found to be 1.28 times lesser than normal concrete, showing a low sorptivity sign indicating better quality of concrete for practical applications. **Novelty:** With the least molarity of 8M, GGBFS & fly ash (50:50) ratio-based GPC, with ambient curing alone, performed higher strength parameters in comparison with normal concrete, with less rate of sorptivity coefficient. GPC processed without heat curing has the ability to expand its application in the construction field, saving energy and costs related to heat curing.

Keywords: Strength parameters; Sorptivity coefficient; Geopolymer concrete; Normal concrete; Ambient curing

1 Introduction

GPC is a greener alternative to ordinary Portland cement-based concrete[1]. GPC is economical, low energy consumption, thermally stable, easily workable, eco-friendly, cementless, and durable[2]. As reported by[3], one of the most important properties of good quality concrete is its low permeability which in turn resists the ingress of water. Also, water absorption in GPC is less compared with normal concrete. Studies also showed an increase in sodium silicate content reduced the initial and final setting time along with a decrease in water absorption [4]. Ground granulated blast furnace slag (GGBFS) with fly ash has been proven to give enhanced strength, and durability with reduced setting time. The study revealed an increase in compressive strength, split tensile strength, density, and an increase in flexural strength by 40% replacement of fly ash by GGBFS. The workability was stiffer, requiring the use of a super plasticizer during the time of casting [5]. According to [6] stream curing achieves the best mechanical properties in comparison with water and thermal curing. As per [7] specimens kept at room temperature acquire higher strength while specimens kept in water fail to achieve target strength. High early strength in GPC can be effectively used in precast industries, such that huge production is possible in a short duration, and breakage during transportation shall be minimized [8]. The binder index combines the effect of the GGBFS to the fly ash ratio and the molarity of the alkaline activator where the strength of the GPC is significantly influenced by varying the binder index. The fly ash and GGBFS combination can be used to produce GPC without the need for heat curing [9]. The strength of GPC increases with an increase in fly ash fineness. It was observed that after a certain fineness of fly ash there is a decrease in the compressive strength and the same pattern for the result is observed for the split tensile test also [10]. GPC based on fly ash alone requires a high curing temperature, making it a challenge for in situ construction. In the past decades, concerns regarding the environment and human health have encouraged research into investigating alternative construction materials with the use of industrial wastes. The sole purpose of this experiment is, therefore, to investigate the possible behavior of GGBFS and fly ash-based GPC by examining its sorptivity coefficient and mechanical properties. The majority of the literature review mostly focused on fly ash-based geo-polymer concrete with varying molarity subjected to heat curing for different periods. GPC processed without heat curing has the ability to expand its application in the construction field, saving energy and costs related to heat curing. Hence, this study is aimed at developing GGBFS and fly ash-based GPC while keeping the alkaline solution ratio at 1:2.1 and molarity constant at 8M with ambient curing for different curing periods.

2 Methodology

2.1 Materials

1. OPC 43 grade Ultratech cement from local market
2. Fly ash and GGBFS are 2 binder materials used. Fly ash procured from thermal power plant raichur and GGBFS from JSW Bellary.
3. Sodium hydroxide and sodium silicate picked as activators. Sodium hydroxide flakes comprising of 98% purity sodium silicate in liquid form obtained from Peenya industrial area, Bengaluru.
4. Fosroc SP 30 super plasticizer
5. M-sand commonly referred to as manmade sand, is a particular kind of sand made from crushed granite boulders. In the current experiment, manufactured sand (M-sand) that is readily accessible in the area and smaller than 4.75 mm in size was used. The M-different sand's physical characteristics were tested by IS 2386: 1963, and the results of the tests are displayed in Table 1 . The compressive and flexure strengths of concrete are seen to rise when the proportion of M-Sand is raised to the appropriate level of 50%, suggesting that M-Sand may be utilized as a partial substitution for natural sand in the concrete. Table 1 shows the characteristics of M-sand being used for the present research work.

Table 1. Characteristics of M-Sand

S. No	Property	Testing Score	Typical value (IS 383: 2016)	Method of a test, Ref. to
1	Specific gravity	2.64	3.2 Maximum	IS: 2386 (Part III) – 1963
2	Density of bulk, kg/m^3	1660	-	IS: 2386 (Part III) – 1963
3	Grading Zone	Zone II	Zone I to IV	IS: 2386 (Part I) – 1963
4	Water absorption, %	2.5	Max. 5	IS: 2386 (Part III) – 1963

2.2 Mix Proportions

M20 and M40 are the two grades utilized for GPC and normal concrete. A sodium silicate to sodium hydroxide ratio of 2.1 and molarity of 8M for all grades, with a binder ratio of 0.23 for M40, and 0.29 for M20 were considered as part of the design mix in order to obtain the requisite workability for GPC. The design mix is being carried out in accordance with IS 10262-2019. Mix proportions of each grade given inTables 2 and 3 .

Table 2. Mix proportions for GPC

Concrete Grade	BinderMaterial (Kg/m3)	M-sand (Kg/m3)	Coarse aggregate (Kg/m3)	Sodium hydroxide (Kg/m3)	SodiumSilicate (Kg/m3)	Molarity	Liquid Binder Ratio	Water / Solid Ratio
M40	400	674.52	1300.13	91.43	100.57	8M	0.48	0.23
M20	275	802.56	1250	91.67	100.84	8M	0.70	0.70

Table 3. Mix proportions for normal concrete

Concrete Grade	Cement (Kg/m3)	M-sand (Kg/m3)	Coarse aggregate (Kg/m3)	Water/cement Ratio	Super plasticizer
M40	412	661	1259	0.36	0.8%
M20	384	681.73	1150	0.5	NA

2.3 Preparation of alkaline solution

Sodium hydroxide was initially mixed in water followed by the addition of sodium silicate and left for cooling. A solution is prepared 24 hours prior to casting of GPC, as engaging warm solution decreases the workability and strength of concrete[11].

2.4 Casting and Curing of Specimens

The casting procedure for GPC followed a similar pattern to that of normal concrete, where a mixture machine was engaged. Dry ingredients m-sand and aggregate (coarse) first mixed thoroughly for approximately 2 minutes followed by adding fly ash and GGBFS and mixed again for 1 minute. Alkaline activators were added and mixed for 2 minutes to attain a homogeneous mixture. The moulds were cleaned with a dry cloth and oiled for the smooth release of the specimens. Fresh concrete was poured into the moulds in 3 layers, giving 25 blows to each layer to gain maximum compaction. Specimens were given a smooth finish by a trowel for the top surface. 15 cubes with sides 150mm; 12 cylinders with dia 150mm, 300mm length, and 12 beams of 100mm in depth and width with 550mm length being cast for each mix. Casted specimens of GPC and normal concrete are shown in Figures 1 and 2.

Fig 1. Casted GPC specimens

Fig 2. Casted normal concrete specimens

2.5 Curing

24 hrs after casting, specimens were demoulded and geo-polymer concrete (GPC) specimens were kept for ambient curing at temperature 27^{o}-36^{o}C. Normal concrete specimens were kept for water curing at 25^{o}-32^{o} C.

2.6 Testing Methods

2.6.1 Slump Test

A slump cone test was performed to evaluate the workability of fresh concrete, in accordance with IS 11989-1959, slump obtained for GPC = 130mm and normal concrete = 120mm.

2.7 Test for Mechanical Properties

Casted specimens being tested for compression, split tensile, and flexural strength for 7, 28, 56 & 90 days. An automatic compression testing machine with a loading capacity of 2000 kilo Newton is being used, rate of loading as per IS 516-2021 mentioned in the Table 4.

Table 4. Rate of loading

Rate of Loading	Compression	14N/mm/min
	Split tensile	1.2 to 2.4 $\times$ π/2$\times$ l $\times$ d N/min
	Flexure	1.8kN/min for 100mm specimens

2.8 Sorptivity Coefficient Test

Sorptivity test being conducted for 3 cube specimens for each mix after 28 days. The initial weight of the dry specimen noted as w1. Epoxy is used to coat all sides of specimens except for the base and is dipped 5mm allowing movement of water through the base of cube specimen. 60 minutes reading with an interval of 10 minutes were noted w2 with the help of a stop watch.

Sorptivity coefficient calculated as per ASTM C 1585-2004

$Sc = I / \sqrt{t}$

$I = DW / a \times d$

Sc = sorptivity coefficient

DW = interval reading w2- initial weight w1

A = base area in mm2

D = water density

$\sqrt{t}$ = time elapsed

3 Result and Discussion

Considering both economic and environmental factors, GPC is the most practical alternative to ordinary concrete[12]. To further promote GPC mixes as an ecologically friendly building material, mineral additives can be used to design for ambient temperature curing conditions[13]. Also, it was evident that mechanical properties improved with higher amounts of activator[14]. Aggregate type and alkaline solution ratio have a significant impact on the density of the GPC. The density of normal concrete was found 23974.07 Kg/m3 in this work while the density of GPC was found to be 2408.89 Kg/m3 making GPC specimens denser in comparison with the normal concrete. As reported by[15] most studies focus on compressive strength. While, flexural strength often determines the shaping ability of concrete itself, which has a significant impact on the failure mode of concrete. The strength of a concrete material plays a crucial function. One of the key final properties that determine the strength of a concrete that has been designed is its compressive strength. Additionally, it is crucial to examine the split tensile and flexure strength for its mode of failure in order to do a thorough analysis of the mechanical properties of the concrete. The only difference we find is in the curing process because the casting process and the equipment used to prepare geo-polymer concrete are identical to those used to prepare regular concrete. The ambient curing method used in this study for the GPC specimens used less water than the traditional water curing method used for normal concrete. With a 2% addition of micro silica in the geo-polymer concrete mix, an increase was observed in compressive and tensile strength. Also, ambient conditions showed the least compressive and tensile strength when compared with steam curing. Steam-curing geo-polymer specimens with 100% copper slag tensile and compressive strength were 55.1 and 54.8% higher when compared to the tensile strength during the 28-day curing period[16]. Ash inclusion in geo-polymer concrete in large quantities provides high compressive strength, with 12M molarity and 100% composition of fly ash; the compressive strength was up to 43.32Mpa[17]. As per[18] the effect of heat curing at 1200 C on the strength evolution in brown coal fly ash, the polymerization progressed more rapidly for the mortar specimens than the concrete specimens with 12 to 14 hr providing curing time for 50mm mortar cubes and 24 hr being the optimum time for 100mm concrete cubes. With molarity of 8, 10, 12, 14, 16 18 and 20 and usage of steam curing[19] studied durability on fly ash-based GPC. As reported by[20] curing temperature, liquid binder ratio, and sodium silicate content are the independent variables to predict the compressive strength of fly ash-based GPC. With the increase in activators i.e. 1:2, 1:2.5, and 1:3 mechanical properties strength also increased. The strength of GPC specimens improved with an increase in curing time[21]. As fly ash content increases the air content of GPC mixes decreases[22]. The use of natural fiber (coconut fiber) with 100% fly ash was studied by[23] replacing fiber percentage with 0, 0.25, and 0.5 with a molarity of 12 and 16 M. The test revealed compressive strength of 40.16Mpa at 28 days with 16M with 0.5% of natural fiber to that of 12.17Mpa with 0% natural fiber. With a molarity of 12M and 50% fly ash, GPC specimens exposed to the elevated temperature of 1000 C showed an increase in the strength of mechanical properties, at the same time exposure to a temperature of 3000 C decreased the strength of mechanical properties[24]. With 20% fly ash and 80% metakaolin studied by[25] with a molarity of 12 M and 1:3 alkaline liquid ratio it was found., a 9% increase in compressive strength, 18.6% for tensile strength, and 23.6% for flexural strength. The effect of fly ash blending on self-compacting GPC was studied by[20] by replacing 10% class C fly ash with class F fly ash. Results showed that the inclusion of class C fly ash did not show any detrimental effect on self-compacting geo-polymer concrete. Increase in curing temperature in the range of 30 to 90 C, compressive strength also increases[21]. The molarity of sodium hydroxide, curing temperature, and curing time, lead to changes in strength[22]. Concrete samples cured at heating temperatures up to 1000C increased compressive strength; however, samples cured above 1000C led to a loss in compressive strength[23]. GPC with fly ash based experienced a high rate of strength loss in its mechanical properties during elevated temperatures up to 2000C[24]. As reported by[25] curing temperature, liquid binder ratio, and sodium silicate content are the independent variables to predict the compressive strength of fly ash-based GPC. With the increase in activators i.e. 1:2, 1:2.5, and 1:3 mechanical properties strength also increased. Super plasticizer is not being used in the present work design mix of GPC, as the workability achieved was accurate. All concrete grades underwent the trials, which were followed as per the design mix. The strength parameters with 8M molarity and binder ratio of 50:50 and the alkaline ratio of 1:2.1, for all trial mixes of M20 & M40 GGBFS &, fly ash-based GPC in comparison with normal concrete have been recorded.

3.1 Compressive Strength

Alumina silicate material is activated with sodium hydroxide to develop GPC which plays a vital role in bonding solid particles with a molarity of 8M kept constant and alkaline solution ratio being 1:2.1, compressive strength of M20, M40 GPC, and normal concrete shown in Table 5

The average compressive strength of M40 GPC was 46.29Mpa, 56.46Mpa; 57.84Mpaa & 58.58Mpa for 7, 28, 56, and days. While M40 Normal concrete was 31.86Mpa, 49.44Mpa, 52.7Mpa & 53.1Mpa for 7, 28, 56, and 90 days. Results revealed that the compressive strength of M40 GPC specimens increased by 45.29%, 14.19%, 9.75%, and 2.07% for 7, 28, 56, and 90 days respectively.

Similarly, the average compressive strength of M20 GPC was 32.97Mpa, 42.18Mpa, 44.31Mpa, and 45.95Mpa for 7, 28, 56, and 90 days. While M20 normal concrete was 20.43 Mpa, 29.33Mpa, 30.45Mpa, and 30.44Mpa for 7, 28, 56, and 90 days. Results showed the compressive strength of M20 GPC specimens increased by 60.05%, 43.81%, 45.51%, and 50.95% for 7, 28, 56, and 90 days respectively. It was observed, the strength of M40 GPC increased in the first 7 to 28 days at ambient curing and later not much gain in strength. Likewise, M20 GPC in comparison to M20 normal concrete performed consistently for all curing periods and not much drop in strength.

3.2 Split Tensile Strength

Results of split tensile strength of M20, M40 GPC, and normal concrete shown in table 6:With ambient curing, the results revealed the same pattern as for compressive strength; it was observed the average split tensile strength for M40 GPC was 4.88Mpa, 5.08Mpa, 5.12Mpa and 5.17Mpa for 7, 28, 56 and 90 days. While M40 normal concrete was 3.19Mpa, 4.17Mpa, 4.28Mpa and 4.40Mpa respectively. Results revealed that the tensile strength of M40 GPC specimens increased by 52.97%, 21.82%, 19.62%, and 17.5% for 7, 28, 56, and 90 days respectively.

Similarly, the average split tensile strength for M20 GPC was 2.98Mpa, 4.11Mpa, 4.25Mpa, and 4.34Mpa for 7, 28, 56, and 90 days. While M20 normal concrete was 2.03Mpa, 2.36Mpa, 2.53Mpa and 2.55Mpa respectively. Results showed the tensile strength of M20 GPC specimens increased by 46.7%, 74.15%, 67.98%, and 70.19% for 7, 28, 56, and 90 days respectively. The presence of GGBFS in equal percentage with fly ash adding more calcium and sodium with aluminum and silicon developed calcium silicate hydrate resulting in dense microstructure increasing the strength of GPC. It was observed that M20 and M40 GPC had better performance in comparison with M20 and M40 normal concrete.

3.3 Flexure Strength

Results of flexure strength of M20, M40 GPC, and normal concrete shown in table 7: Flexure strength for M40 GPC was 5.01Mpa, 6.94Mpa, 7.07Mpa, and 6.82Mpa and M40 NC was 3.71Mpa, 4.88Mpa, 5.17Mpa and 6.01Mpa for 7, 28 56 and 90 days. Results showed flexure strength of M20 GPC specimens in comparison with M20 normal concrete increased by 35.04%, 42.21%, 36.75%, and 13.47% for 7, 28, 56, and 90 days, respectively. It was observed that not much gain in strength after the first 28 days. Similarly, the average flexure strength for M20 GPC was 4.89Mpa, 5.80Mpa, 5.61Mpa, and 6.15Mpa for 7, 28, 56, and 90 days. While M20 normal concrete was 3.69Mpa, 4.89Mpa, 5.09Mpa and 5.96Mpa respectively. Results showed the tensile strength of M20 GPC specimens increased by 32.52%, 18.60%, 10.21%, and 3.18% for 7, 28, 56, and 90 days respectively. Extra calcium silicate hydrate development is responsible for the increase in strength.

3.4 Effect of binder index on strength properties

Previous research revealed that compressive strength increased with the binder ratio. The Binder index is defined as the ratio of GGBFS to fly ash and the molarity of the activator solution. The increase in strength, however, does not correspond to the rise in the binder index [26].

3.5 Effect of fineness of fly ash on strength of GPC

The density, compressive strength, and workability all rise as the fineness does lowering the porosity and water absorption capacity of GPC fly ash's fineness plays a crucial role in the construction process.

3.6 Effect of type of curing on strength of concrete

The quality of the concrete is often determined by its 28-day compressive strength. Due to the fact that cement can only be hydrated in water-filled capillaries, curing is required. If enough moisture is available for the cement to hydrate, which can only be ensured by creating favorable temperature and humidity conditions, concrete continues to get stronger over time.

3.7 Sorptivity coefficient (water absorption

The average rate of water absorption (sorptivity coefficient) for M40 NC-0.0385, M40 GPC–0.0285, M20 NC–0.0357 and M 20 GPC–0.0283 mm/min0.5 respectively, water absorption rate from fig 6 of GPC was 1.28 times lesser than normal concrete, which results in durability of the concrete.

Table 5. Compression Strength

Concrete Grade	Curing Type	Parameter	7 DaysStrength in (Mpa)	28 DaysStrength in (Mpa)	56 DaysStrength in (Mpa)	90 DaysStrength in (Mpa)
M40 GPC	Ambient	Compression	46.29	56.46	57.84	58.58
M40 NC	Water		31.86	49.44	52.79	53.1
M20 GPC	Ambient		32.97	42.18	44.31	45.95
M20 NC	Water		20.43	29.33	30.45	30.44

Table 6. Tensile Strength

Concrete Grade	Curing Type	Parameter	7 DaysStrength in (Mpa)	28 DaysStrength in (Mpa)	56 DaysStrength in (Mpa)	90 DaysStrength in (Mpa)
M40 GPC	Ambient	Split Tensile	4.88	5.08	5.12	5.17
M40 NC	Water		3.19	4.17	4.28	4.40
M20 GPC	Ambient		2.98	4.11	4.25	4.34
M20 NC	Water		2.03	2.36	2.53	2.55

Table 7. Flexure Strength

Concrete Grade	Curing Type	Parameter	7 DaysStrength in (Mpa)	28 DaysStrength in (Mpa)	56 DaysStrength in (Mpa)	90 DaysStrength in (Mpa)
M40 GPC	Ambient	Flexure	5.01	6.94	7.07	6.82
M40 NC	Water		3.71	4.88	5.17	6.01
M20 GPC	Ambient		4.89	5.80	5.61	6.15
M20 NC	Water		3.69	4.89	5.09	5.96

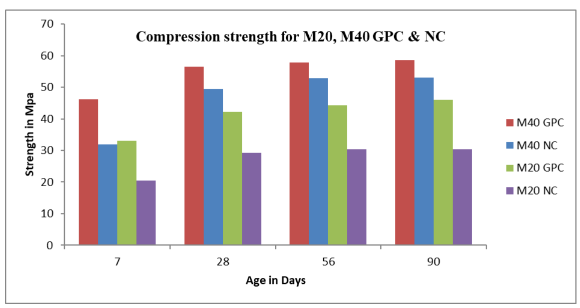

Fig 3. Compression Strength M20, M40 GPC & normal concrete

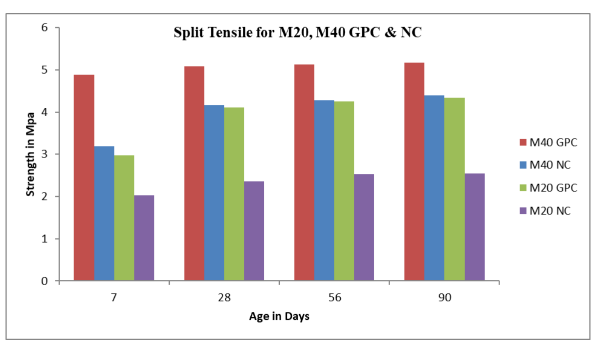

Fig 4. Split Tensile Strength M20, M40 GPC & normal concrete

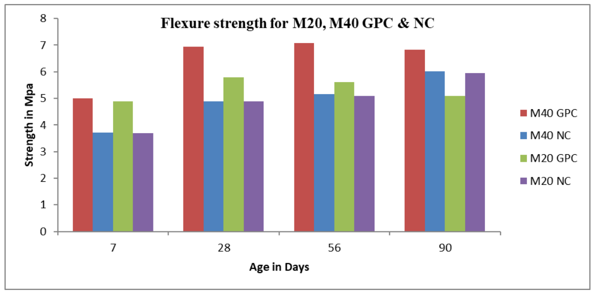

Fig 5. Flexure Strength M20, M40 GPC & normal concrete

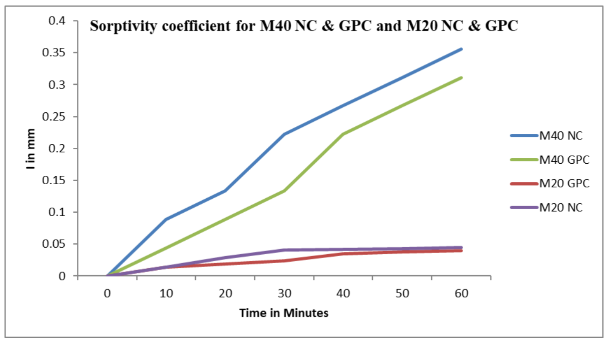

Fig 6. Sorptivity coefficient M20 & M40 GPC & normal concrete

4 Conclusion

GPC, being an ideal replacement for ordinary Portland concrete, can reduce CO2 emissions by using industrial wastes like fly ash and GGBFS. The present work focused on mechanical properties and the sorptivity coefficient is being recorded. The main contents of this paper can be summarized as follows:

- Preparation of GPC requires similar equipment and procedures to that of normal concrete.
- GGBFS makes an excellent binder material with fly ash enhancing the workability.
- Usage of GGBFS with fly ash promotes ambient curing replacing heat curing for fly ash alone-based GPC.
- With molarity kept at 8M with an alkaline solution ratio being 1:2.1, in this research work, it was observed that compression strength of 56.46Mpa for the M40 GPC and 49.44Mpa for M40 normal concrete and 42.18Mpa for M20 GPC and 29.33Mpa for M20 normal concrete was achieved in 28 days. GPC exhibited 14.19% higher strength for the M40 grade and 43.81% higher strength for the M20 grade in comparison with normal concrete.
- Split tensile strength of GPC M20 and M40 grade for 28 days recorded 4.15Mpa and 5.08Mpa.
- Flexure strength of GPC M20 and M40 grade for 28 days was recorded 5.80Mpa and 6.94Mpa, respectively.
- It was observed strength was achieved in the first 28 days, and later there was not much gain in strength for M40 GPC specimens for compressive strength, whereas M20 GPC specimens performed consistently for all curing periods and not much drop in strength.
- The density of GPC is higher due to the better reactivity of alkaline activators with GGBFS and fly ash.
- Water absorption in GPC is 1.28 times less in comparison to normal concrete resulting in the durability of structures.
- The average rate of water absorption (sorptivity coefficient) for M40 NC-0.0385, M40 GPC–0.0285, M20 NC–0.0357, and M 20 GPC–0.0283 mm/min0.5 respectively

In brief, the conclusion can be drawn, by the addition of GGBFS with fly ash can be used to obtain a workable GPC with a binder ratio of 50:50 and alkaline solution ratio of 1:2.1, excluding the use of superplasticizer in mix design, which serves as an excellent alternative material to that of normal concrete. Further, there is a scope for study based on varying molarity with different binder ratios and alkaline solution ratios for each mix of different grades on several parameters.

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