International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I11P219

Volume 70 Issue 11, 178-186, November 2022
© 2022 Seventh Sense Research Group®

Original Article

A Design Mix Procedure and Durability Evaluation of Ggbfs & Fly Ash Based Geo-Polymer Concrete

B. S. Pruthviraj[1], Shrishail B Anadinni[2]

[1,2]*Civil Engineering Department, Presidency University, Bengaluru, Karnataka, India*

[1]*Corresponding Author : pruthviraj.civilengineer@gmail.com*

Received: 06 August 2022 Revised: 08 November 2022 Accepted: 16 November 2022 Published: 26 November 2022

Abstract - *In this research paper, a clear effort has been made to develop a step-by-step design mix procedure for GPC (Geo-Polymer Concrete) using ground granulated blast furnace slag (GGBFS) and fly ash with a 50:50 ratio replacing cement completely with alkaline solution ratio kept at 1:2.1 with a molarity of 8M. Compression and tensile strength for 7 and 28 days for M40 GPC were recorded high as46.29Mpa and* 4.88Mpa for 7 days and *56.46Mpa and 5.08Mpa for 28 days. For durability evaluation, M20 and M40 grades were chosen, and specimens were exposed to5% sulphuric acid, hydrochloric acid, and ammonium sulphate solutions for 28 days. Test specimens of 150mm cubes were cast and cured at ambient temperature for a period of 28 days. The loss in compressive strength for a 5% acidic attack in M40 GPC for 28 days was 12.92% and 31.81% for M20 GPC, respectively, making M40 superior to M20 grade. The loss in compressive strength for a 5% sulphate attack in M40 GPC for 28 days was 3.29% and 2.86% for M20 GPC. Similarly, the loss in compressive strength for a 5% chloride attack in M40 GPC for 28 days was 2.07% and 1.37% for M20 GPC, respectively.*

Keywords - *Design mix, Durability assessment, Fly ash, GGBFS, Geo-polymer concrete.*

1. Introduction

Given that concrete is one of the most essential building materials, infrastructure development would be nearly flat without it. The emissions of CO_2 gas from the cement industries are harmful to human life; hence, in the last few decades, GPC has been one of the new materials that can be used for construction and as a replacement for Portland cement-based concrete. To taper the consumption of Portland cement, Davidovits introduced GPC in the year 1979. The issue of ozone depletion and global warming has made the construction industry increasingly cognizant of the need to employ more environmentally friendly materials. Compared to OPC, geopolymer composites have less energy and a smaller carbon footprint [1]. The increasing demand for concrete for infrastructure development not only depletes natural resources and energy simultaneously but substantially contributes to the release of CO2 into the environment. GPC is cost-effective, energy-efficient, thermally stable, simple to work with, environmental-friendly, cementless, and long-lasting [2].

Construction materials that are better mechanically and durable can be identified as being eco-friendly, such as GPC. With an adequate supply of agricultural waste materials, it is thought to be a suitable replacement for OPC concrete [3]. Geopolymer concrete has demonstrated great strength, minimal shrinkage, and resilience to reinforcement corrosion, resistance to acid and sulphate, resistance to freeze-thaw, fire resistance, and resistance to the reaction of alkali with aggregate [4]. As reported by [5], most studies focused on compressive strength, while flexural strength often determines the shaping ability of concrete itself, which significantly impacts the failure mode of concrete. When industrial wastes like fly ash and ground granulated blast-furnace slag (GGBFS) are added to GPC, benefits like lower carbon dioxide emissions, the capacity to reuse waste materials, preventing the conversion of precious land to dump yards, lower costs, and so on[6]. The ability of geo-polymer materials to efficiently absorb radioactive contamination, heavy metals, dyes, and other pollutants are particularly advantageous for society's future growth. However, the application of geo-polymer materials is more extensive because of their superior characteristics [7]. Despite the conventions of the construction industry, the lack of an appropriate mixture design approach prevents the widespread adoption of GPC in the industry [8]. Many design mixes proposed by past researchers are based on trial-and-error methods. It has been reported by [9] that the liquid in the mix design has a greater impact on the compressive strength created in GPC. As more factors are included, mix design and proportioning of GPC get increasingly complicated, and there is currently no established mix design methodology for creating GPC [10].

Due to their superior mechanical qualities, eco-friendliness, and capacity to utilize a variety of wastes as precursors, geo-polymers have drawn increased attention [11]. With the addition of cementitious ingredients and alkali-activated solutions, geo-polymer concrete has the benefit of replacing cement. In contrast to regular concrete, geo-polymer

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

concrete is a relatively new, cutting-edge, and environmentally friendly engineering material [12]. The high compressive strength and durability make concrete the most commonly used construction material worldwide. Compressive strength and effect of design mix proportions of GPC have been studied in depth; previously, a lack of a proposed design mix exists [13]. To develop GPC, curing conditions, setting periods, workability, alkaline solution to binder ratios, and molarity of an alkaline solution, Na_2SiO_3/NaOH, the ratio is crucial [14]. Compared to hydrochloric acid, sulfuric acid is more hazardous to GPC made from fly ash [15].

Geo-polymer serves just as alternative construction material which can be produced by polymerization technique, with the usage of industrial wastes like fly ash and GGBFS by replacing cement completely and hence providing an eco-friendly engineering construction material. The progress of GPC needs an appropriate design mix to attain the desired strength and workability. However, despite extensive research work carried out, the design mix method for GPC is limited and inadequate. As much previous research focused on heat curing, which puts a challenge on in situ construction, GPC with ambient curing can also be used in construction fields, which saves energy and cost related to heat curing.

Therefore in the present research work, an attempt has been made to put forward a design mix method with step by step procedure for GGBFS and fly ash-based GPC by replacing cement by 100%, with alkaline solution ratio being 1:2.1, keeping molarity constant at 8M for all mix design of GPC, under ambient curing, along with the durability assessment in comparison with normal concrete, exposed to 5% sulphuric acid, 5% hydrochloric acid, and 5% ammonium sulphate.

2. Materials and Methodology

2.1. Binder Material

The binder material employed in this research work was fly ash (class F) procured from Raichur thermal plant and GGBFS procured from JSW Bellary, respectively. A binder proportion ratio of 50:50 has been used in this research work. The specific gravity of GGBFS and fly ash being 2.9 and 2.15, respectively, properties of fly ash and GGBFS are as shown in Tables 1 and 2:

2.2. Cement

OPC 43 grade Ultratech cement, tested as per IS: 8112 (1989), it was found that specific gravity = 3.15, initial setting time = 50 minutes and final setting time = 470 nutes.

2.3. M-Sand

Locally available M-Sand has been used in this research work, and the specific gravity of M-Sand was 2.64 tested as per IS 2386 part 3 (1963).

Table 1. Properties of fly ash (class F)

Components	Percentage
Silicon dioxide	52.9
Aluminum trioxide	33
Ferric oxide	4.1
Titanium dioxide	1.1
Calcium oxide	3.4
Magnesium oxide	0.29
Sulphate	0.29
Loss of ignition	6.12

Table 2. Properties of GGBFS

Components	Percentage
Calcium oxide	41
Silicon dioxide	34
Aluminum oxide	9
Magnesium oxide	9
Color	Grey

2.4 Sodium Silicate (Na_2SiO_3)

CHEMIELINK has procured sodium silicate from Peenya Industrial Area, Bengaluru and a ratio of 1:2.2 to 1:2.4 between Na_2O and SiO_2 is used. The specific gravity was 2.2. Table 3 shows the parameters of sodium silicate.

Table 3. Parameters of sodium silicate

Property	Parameters
Sodium oxide	15.5 %
Sodium oxide/silicon dioxide	1:2.2 to 1:2.4
Color	black liquid

2.5 Sodium Hydroxide (NaOH)

Sodium hydroxide flakes procured from TGV SRAAC LIMITED, Kurnool, Andhra Pradesh, have been used in this research work, having a purity of 98 %. The specific gravity of sodium hydroxide flakes was 1.52. Table 4 shows the specifications of sodium hydroxide.

Table 4. Specifications of sodium hydroxide

Specifications	Results Normal Range
Purity as NaOH (%)	98.0
Iron as Fe (ppm)	7.3
Chlorides as NaCl (%)	0.045
Carbonate as Na_2CO_3	0.42

2.6. Alkaline Activator Solution

Sodium hydroxide with sodium silicate is mixed at room temperature and kept for 24 hours before use, as an engaging, warm solution decreases the workability and strength of concrete [16], the molarity of 8M has been used in the research work, where 1M is equal to 40gms of NaOH mixed in 1 liter of water. Hence, 8M=320gms of NaOH has been used in 1 liter of water.

2.7. Casting of Specimens

The design mix of GPC has been carried out in accordance with IS 10262 – 2019 specifications.

Initially, moulds were cleaned with a dry cloth and oiled for the smooth release of the specimens. The specimens were cast using 150 mm ×150 mm cubes for compression with a cylinder of diameter, 150mm with height, and 300mm for tensile strength. The casted GPC specimens were demoulded after 24 hours and kept for curing at an ambient temperature of 27º-36ºC. Table 5 lists the design mix proportions for GPC & NC as of 10262-2019. Tables 6 and 7 list the average strength result for compression and tensile.

2.8. Durability Test

Ammonium sulphate, sulphuric acid, and hydrochloric acid have been used for the durability evaluation of GPC and normal concrete. For sulphate, acid, and chloride attacks, 5% of the diluted solution by volume of water has been used. GPC specimens were cured at ambient temperature and water cured for normal concrete for 28 days and were allowed to dry for 24 hours, and the weight of cubes was noted (W_1).

The cubes were immersed in the solution, prepared for 28 days, and then removed by allowing drying for 24 hours. The weights of the specimens were noted (W_2) and tested for compressive strength. Specimens subjected to acid, sulphate, and chloride attacks are shown in figs 1, 2, and 3.

Fig. 1 GPC & NC specimens with acid attack

Fig. 2 GPC & NC specimens with sulphate attack

Fig. 3 GPC & NC specimens with chloride attack

The loss in weight due to concrete deterioration was calculated using the formula.

Loss in weight = $(\boldsymbol{W1 - W2 \div W1}) \times \mathbf{100}$
W_1 = Initial weight (before immersion)
W_2 = Final weight (after immersion)

2.8.1. Similarly

The loss in strength due to concrete deterioration was calculated using the formula.

Loss in strength = $(\boldsymbol{S1 - S2 \div S1}) \times \mathbf{100}$
S_1 = Initial strength (before immersion)
S_2 = Final strength (after immersion)

3. Step By Step Procedure of Design Mix

3.1. Mix Proportioning

a) Characteristic compressive strength at 28 days as per IS 10262-2019

b) The specific gravity of the constituent of concrete
c) Type and size of aggregates
d) Selection of liquid binder ratio and alkaline activators
e) Calculation of water in activator content
f) Aggregate calculation
g)

3.2. Air Content

The approximate amount of entrapped air to be expected in normal non-entrained air) concrete as per (IS 10262-2019) is shown in Table 8.

4. Design Mix for M40 Grade Gpc

As per the design mix proportioning data, M40 grade mix proportion is carried out

a) Compressive strength (characteristic) f_{ck} at 28 days = 40Mpa
b) Specific gravity (M-Sand) = 2.64
c) Specific gravity (Coarse Aggregate) = 2.74
d) Specific gravity (Fly ash) = 2.15
e) Specific gravity (GGBFS) = 2.9
f) Specific gravity (NaOH) = 1.52
g) Specific gravity of Na_2SiO_3 = 2.2
h) Workability : 75-100mm slump
i) Molarity : 8M
j) Nominal size of aggregate : 20mm (maximum)
k) Binder content : 300 kg/m^3 (minimum)
l) Sodium silicate/sodium hydroxide = 2.1
m) Aggregate (Fine) = M-Sand
n) Aggregate (Coarse) : 20mm (angular)
p) Liquid to binder ratio = 0.23

Table 8. Air content

Maximum nominal size of aggregate in mm	Entrapped air, as a percentage of the volume of concrete
20	1.0

4.1. Activator Content

The maximum amount of water for $1m^3$ of concrete as per (IS 10262: 2019) is shown in Table 9

Table 9. Maximum amount of water for $1m^3$ of concrete

Nominal maximum size of aggregate (mm)	Maximum water content (Kg/m3)
10	208
20	186
40	165

From table 9, the amount of water for the nominal maximum size of aggregate is 186 kg for the slump of 50 mm.

To increase the slump to 75 mm, we need to increase it by 25 mm. IS code recommends increasing water by About 3% for every 25 mm slump added. Similarly, 6% for 100mm, so for 25 mm, we have (3%)

$= 186 + 186 \times (3/100)$
$= 191.58$ liters
$= 192$ liters

4.2. Liquid Binder Ratio

From IS 10262-2019, liquid-to binder ratio is taken as 0.48 for compressive strength of 40 Mpa

4.3. Binder Material

Fly ash and GGBFS are 2 binder materials used, hence

Binder material (Bm) = Ac / 0.48
= 192 / 0.48
$= 400 \text{ kg} / m^3 > 300 \text{ kg} / m^3$

Hence OK

A ratio of 50:50 Fly ash and GGBFS hence (200 Kg / m^3 each)

4.4. Alkaline Activators (AA)

Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) are chosen as activators

Let, Na_2SiO_3 to NaOH = S = 2.1

Then, Quantity of ac = quantity of (Na_2SiO_3 + NaOH)
= quantity of (S X NaOH + NaOH)
= quantity of NaOH (S + 1)

Quantity of NaOH (QNaOH)
= Quantity of ac / (S +1)
= 192 / (2.1+1)
= 62 kg/m^3

Quantity of Na_2SiO_3 (QNa_2SiO_3)
= S × QNaOH
= 2.1 ×62
= 130 kg/m^3

4.5. Water in Activator Content

The water-to-solid ratio is a critical element in the construction of GPC mixtures. The solid percentage in NaOH and Na_2SiO_3 is taken as 45.5% and 34.5%, respectively.

Let PNaOH and PNa_2SiO_3 be the solids percentages in sodium hydroxide and sodium silicate, respectively.

Water Content = Quantity of water in (NaOH + Na_2SiO_3)

Quantity of water in a sodium hydroxide (QNaOH)
= QNaOH – (PNaOH x QNaOH)
= QNaOH (1- PNaOH)
= 62(1-0.345)
= 40.61 kg/m^3

Quantity of water in Sodium silicate
(QNa2SiO3) = QNa2SiO3 – (PNa2SiO3 x QNa2SiO3)
= QNa2SiO3 (1 -PNa_2SiO_3)
= 130(1-0.455)
= 70.85 kg/m^3

Total = *quantity of water*
= (NaOH + Na2SiO_3)
= 111.46 kg/m^3

21.4 kg of solids has been dissolved in 40.61 kg of water to prepare an 8 Molar solution for the above design mix, and 70.85 kg of water for sodium silicate out of 130 kg has been used. The total water quantity is said to be found at 111.46 kg/m^3. Hence the mix design contains 480.55 (400 + 21.4 + 130 - 70.85) kg/m^3 of concrete. Hence, the water-to-solid ratio is subsequently sustained at 0.23 (111.46/480.55) in this design mix.

4.6. Total Aggregates

Considering

B_{M1} = fly ash and B_{M2} = GGBFS
C_V = Concrete volume
T_V = Total volume of aggregates
B_V = Binder volume
WNaOH = volume of NaOH
W Na_2SiO_3 = volume of Na_2SiO_3
Sg B_{M1} = specific gravity for fly ash
Sg B_{M2} = specific gravity for GGBFS
Sg NaOH =specific gravity for sodium hydroxide
Sg Na_2SiO_3 = specific gravity for sodium silicate
W_A = Entrapped air (1%) from table 8

Concrete volume

$$(C_V) = T_V + B_V + WNaOH + WNa2SiO_3 + W_A$$

Calculating for 1 m^3 of concrete we have

$$T_V + B_V + WNaOH + WNa2SiO_3 = 0.99$$

$$T_V = 0.99 - [(B_{M1}/ Sg\ B_{M1})+(B_{M2} / Sg\ B_{M1}) + (QNaOH / Sg\ NaOH) + (QNa_2SiO_3 / Sg\ Na_2SiO_3)) \times (1/1000)]$$

T_V = 0.99- [(200/2.15) + (200/2.9) + (62/1.52)+ (130/2.2)) x (1/1000)]
= 0.73 m^3

4.7. M-sand and Coarse Aggregate Calculation

Let a% = M-sand percentage
b% = Coarse aggregate percentage

Quantity of M sand (Qms)
= Sg ms ×1000 (a% × T_V)
= 2.64 ×1000 (0.35 × 0.73)
= 674.52 kg/m^3

Quantity of coarse aggregate (Qca)
= Sg ca × 1000(b% × T_V)
= 2.74 × 1000 (0.65 × 0.73)
= 1300.13 kg/m^3

Hence GPC M40 grade ratio
= 1: 1.68: 3.25: 0.48

Table 5. Design mix proportions for M40 GPC and M40 NC

Concrete Grade	Binder (Kg/m3)	M-Sand (Kg/m3)	Coarse Aggregate (Kg/m3)	Sodium hydroxide (Kg/m3)	Sodium Silicate (Kg/m3)	Liquid to binder	Superplasticizer
M40 GPC	400	674.52	1300.13	91.43	100.57	0.48	NIL
M40 NC	412	661	1259	NIL	NIL	0.36	0.8%

Table 6. Compression strength results for 7 & 28 days

S. No	Age of concrete	Load in (kN)		Average Strength (Mpa)		Density (kg/m^3)	
		M40 GPC	M40 NC	M40 GPC	M40 NC	M40 GPC	M40 NC
1	7 days	1054.33	717.03	46.29	31.86	2408.89	2394.07
2	28 days	1270.4	994.03	56.46	49.44		

Table 7. Tensile strength results for 7 & 28 days

S. No	Age of concrete	Load in (kN)		Average Strength (Mpa)		Density (kg/m^3)	
		M40 GPC	M40 NC	M40 GPC	M40 NC	M40 GPC	M40 NC
1	7 days	345	225.73	4.88	3.19	2408.89	2394.07
2	28 days	359.53	294.6	5.08	4.17		

Table 10. GPC and normal concrete exposed to acid attack for 28 days

S. No	Concrete Grade	Average weight of cubes in (kg)		Percentage (%) loss in weight	Average Strength in (Mpa)		Percentage (%) loss in compressive strength
		Initial (W1)	After 28 days (W2)		Before Acid attack	After Acid attack	
01	M40 NC	8.15	7.63	6.38	49.44	35.05	29.10
02	M40 GPC	8.33	8.11	2.64	56.46	49.16	12.92
03	M20 NC	8.08	7.46	7.67	29.33	19.24	34.40
04	M20 GPC	8.27	8.19	0.96	42.18	28.76	31.81

Table 11. GPC and normal concrete exposed to chloride attack for 28 days

S. No	Concrete Grade	Average weight of cubes in (kg)		Percentage (%) loss in weight	Average Strength in (Mpa)		Percentage (%) loss in compressive strength
		Initial (W_1)	After 28 days (W_2)		Before Chloride attack	After chloride attack	
01	M40 NC	8.00	7.94	0.75	49.44	46.85	5.23
02	M40 GPC	8.13	8.05	0.95	56.46	55.29	2.07
03	M20 NC	8.19	8.13	0.73	29.33	27.36	6.71
04	M20 GPC	8.15	8.06	1.10	42.18	41.6	1.37

Table 12. GPC and normal concrete exposed to sulphate attack for 28 days

S. No	Concrete Grade	The average weight of cubes in (kg)		Percentage (%) loss in weight	Average Strength in (Mpa)		Percentage (%) loss in compressive strength
		Initial (W_1)	After 28 days (W_2)		Before sulphate attack	After sulphate attack	
01	M40 NC	8.31	8.10	2.52	49.44	43.17	12.68
02	M40 GPC	8.35	8.19	1.91	56.46	54.60	3.29
03	M20 NC	8.16	7.98	2.20	29.33	28.13	4.09
04	M20 GPC	8.29	8.20	1.08	42.18	40.97	2.86

5. Results and Discussion

Tests were conducted in accordance with the preceding mix design; a workable slump of 80mm was achieved with a liquid binder ratio of 0.48. GPC exhibited a glossy-like appearance in its new state. It can be seen clearly where the slump increases with the water-cement ratio in normal concrete same behavior were observed for GPC. Specimens were cured at an ambient temperature of 27^{o}-36^{o}C. Since GGBFS is used along with the fly ash, the specimens can be cured at ambient temperature, whereas the GPC with fly ash alone requires heat curing. The present design mix considers the liquid-to-binder ratio and the water-cement ratio.

Additionally, it was observed that GPC possessed a sticky nature and delayed setting time. By replacement of m-sand with normal sand, there was no such difference in the strength [17]. The density of GPC was higher due to the better reactivity of alkaline activators with GGBFS and fly ash [18]. With a molarity of 13M and a liquid binder ratio of 0.35, fresh GPC was viscous, dark in color and cohesive [19]. In previous research work carried out by [17-19-20], researchers have used superplasticizers in the range of 1% to 3% to improve workability, while in this present work, the workability was achieved without the use of superplasticizers. Further, the results obtained for 28 days using the proposed design mix; from Tables 6 & 7 exhibited exceptional compressive strength of 56.46Mpa and tensile strength of 5.08Mpa. On that account, it can be seen that a superior compressive strength could be achieved by adopting the design mix procedure for all grades of GGBFS and fly ash-based GPC.

5.1. Density

GPC produced with the help of an alkaline activator has better reactivity to GGBFS and fly ash resulting in denser concrete, in return giving superior compressive strength. The density of normal concrete in the present work was 2394.07 kg/m^3, while the density of GPC was 2408.89 kg/m^3.

5.2. Resistance to Acid Attack

Since the majority of the previous research work focused only on fly ash-based GPC, the present work focuses on GGBFS and fly ash-based GPC. Table 10 exhibits weight loss and compressive strength loss. Accordingly, the specimens were exposed to a 5% acid attack for 28 days for M20 and M40 GPC and normal concrete. With an exposure for 28 days, it was reported that the percentage loss in weight was 6.38% for M40 NC, 2.64% for M40 GPC, 7.67% for M20 NC, and 0.96% for M20 GPC. Similarly, the percentage loss in compressive strength was 29.10% for M40 NC, 12.92% for M40 GPC, 34.40% for M20 NC, and 31.81% for M20 GPC. From 7-45 days of exposure to sulphuric acid, the percentage loss in strength was 18-28% in normal concrete and 12-20% in GPC [21]. With a high fly ash content, the rate of strength loss decreased [22]. The observed deterioration was linked to the de-polymerization of the alumina silicate polymers in acidic environments and the creation of zeolites, which sometimes resulted in a significant loss of strength [33]. The present work revealed that the strength and mass loss was less in GPC than in normal concrete with 5% sulphuric acid.

5.2.1. Resistance to Chloride Attack

Table 11 exhibits weight loss and compressive strength loss. Accordingly, the specimens were exposed to a 5% chloride attack for 28 days for M20 and M40 GPC and normal concrete. The deterioration being negligible in GPC, with exposure for 28 days, it was reported that the percentage loss in weight was 0.75% for M40 NC, 0.95% for M40 GPC, 0.73% for M20 NC, and 1.10% for M20 GPC. Similarly, the percentage loss in strength was 5.23% for M40 NC, 2.07% for M40 GPC, 6.71% for M20 NC, and 1.37% for M20 GPC. With 2% chloride solution, blended fly ash and slag GPC corrosion was lower than ordinary concrete. It was also reported that, even when the concrete is contaminated with high levels of chloride, embedded rebar in geopolymer-based fly ash and slag concrete is better protected against corrosion than rebar in OPC concrete [24]. With 6%, 11%, and 15% of chloride solutions studied by [25], it was reported that the strength fluctuation in GPC mortar was higher in sulphuric acid than in chloride solutions. As reported by [34], with a molarity of 12M and a curing period of 90 days, GPC gains higher strength as curing is prolonged in wet conditions. It can be noted that in the present work, the loss in compressive strength in comparison with an acidic attack is less in a 5% chloride attack, while M4O and M20 GPC performed better in comparison with M40 and M40 normal concrete, making GPC an outstanding sea water zone construction material.

5.3. Resistance to Sulphate Attack

The gypsum precipitation and decalcification of C-S-H caused by the sulphate assault on the magnesium ions reduce the binding capacity of C-S-H, which reduces the strength and adhesion of concrete [27]. Table 12 exhibits weight loss and compressive strength loss; the specimens were exposed to 5% sulphate attack for 28 days for M20 and M40 GPC and normal concrete. With exposure for 28 days, it was reported that the percentage loss in weight was 2.52% for M40 NC, 1.91% for M40 GPC, 2.20% for M20 NC, and 1.08% for M20 GPC. Similarly, the percentage loss in strength was 12.68% for M40 NC, 3.29% for M40 GPC, 4.09% for M20 NC, and 2.86% for M20 GPC. No changes in the visual appearances of GPC specimens in comparison to normal concrete were observed. The presence of calcium hydration in GPC gave an efflorescence presence for the specimens. With a 5% solution, low calcium content and low water absorption, GPC specimens were less sensitive to attack than normal concrete [28]. For alkali-activated concrete pozzolan concrete, exposure to sulphate solution was greater by 5.1% and less than 7% of weight [29]. As reported by [30], after 24 weeks of exposure, mass losses in GPC and normal concrete specimens were 8.1% and 14.2%, respectively. The main geopolymerization products are less sensitive to sulphate attack because of the high calcium content in the parent material [31]. It can be noted that in the present work, the loss in weight in GPC was in the range of 1% to 3%.

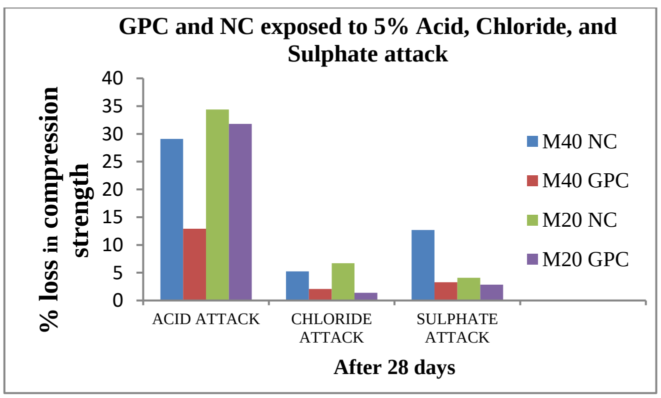

Fig. 4 Percentage loss in compressive strength

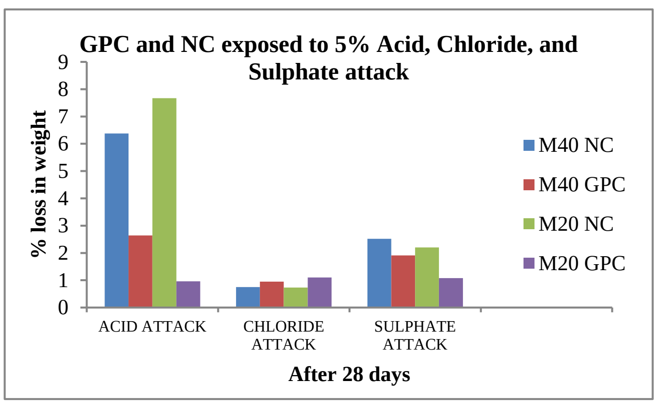

Fig. 5 Percentage loss in weight

6. Conclusion

The present work focuses on the design mix and durability evaluation of M20 and M40 GPC; the results are recorded. The main contents of this paper can be summarized as follows:

- By increasing molarity, GPC strength can be increased.
- Precautions and trained workers are needed to handle fresh concrete, as much heat is generated while preparing the alkaline solutions
- The density of GPC was higher due to better reactivity of alkaline activators with GGBFS and fly ash
- Ambient curing in place of heat curing which is effortless
- Due to sodium silicate's sticky nature, a delay in the setting time of GPC can be observed
- GPC demonstrated higher compressive strength of 56.46 MPa and tensile strength of 5.08 MPa under ambient curing, according to present research.
- GPC and normal concrete specimens both reported weight and strength loss when exposed to acidic, chloride and sulphate attack
- The loss in compressive strength for a 5% acidic attack in M40 GPC for 28 days was 12.92% and 31.81% for M20 GPC, respectively, making M40 superior to M20 grade
- The loss in compressive strength for a 5% chloride attack in M40 GPC for 28 days was 2.07% and 1.37% for M20 GPC, respectively
- The loss in compressive strength for a 5% sulphate attack in M40 GPC for 28 days was 3.29% and 2.86% for M20 GPC, respectively
- Loss in compressive strength and weight is more in acid attack in comparison with chloride and sulphate attack
- No changes in the visual appearances of GPC specimens in comparison to standard concrete were observed for sulpate attack for 28 days

In a nutshell, the results revealed with the addition of GGBFS along fly ash can be used to create a workable GPC with a binder ratio of 50:50, molarity of 8M, and alkaline solution ratio of 1:2.1, excluding the use of superplasticizer in mix design, which serves as an excellent substitute material to that of normal concrete.

GPC exhibited less weight loss and strength than normal concrete, with 5% of acid, chloride, and sulphate solutions at 28 days.

Additionally, there is room for research based on altering molarity, different binder ratios, and varied alkaline solution ratios for every mixture of various grades on a number of characteristics.

References

[1] Ahmed, Hemn, Mahmood, Lavan, Muhammad, Muhammad, Faraj, Rabar, Qaidi, Shaker, Hamah Sor, Nadhim, Mohammed, Ahmed and Mohammed, Azad, "Geopolymer Concrete as a Cleaner Construction Material: An Overview on Materials and Structural Performances," *Cleaner Materials,* vol. 5, pp. 100111, 2022. Crossref, https://doi.org/10.1016/j.clema.2022.100111

[2] Manvendra Verma, Nirendra Dev, Ibadur Rahman, Mayank Nigam, Mohd. Ahmed and Javed Mallick, "Geopolymer Concrete: A Material for Sustainable Development in Indian Construction Industries," *Natural Resources Conservation*, vol. 12, no. 4, pp. 1-24, 2022. Crossref, https://doi.org/10.3390/cryst12040514

[3] Imtiaz, Lahiba, Rehman, Sardar, Memon, Shazim, Khan, Muhammad and Faisal, Arbab, "A Review of Recent Developments and Advances in Eco-Friendly Geopolymer Concrete," *Applied Sciences,* vol. 10, pp. 7838, 2020. Crossref, https://doi.org/10.3390/app10217838

[4] Ganesh, Chithambar and Muthukannan, Muthiah, "A Review of Recent Developments in Geopolymer Concrete," *International Journal of Engineering and Technology,* vol. 7, no. 2, pp. 696-699, 2018. Crossref, https://doi.org/14419/ijet.v7i4.5.25061

[5] Zhong Xu, Zhenpu Huang, Changjiang Liu, Xiaowei Deng, David Hui and Shujin Deng, from the *Journal Reviews on Advanced Materials Science,* vol. 60, no. 1, pp. 158-172, 2021. Crossref, https://doi.org/10.1515/rams-2021-0021

[6] Parathi S, Nagarajan P and Pallikkara S.A, "Ecofriendly Geopolymer Concrete: A Comprehensive Review," *Clean Tech Environ Policy*, vol. 23, pp. 1701-1713, 2021. Crossref, https://doi.org/10.1007/s10098-021-02085-0

[7] Peiliang Cong and Yaqian Cheng, "Advances in Geopolymer Materials: A Comprehensive Review," *Journal of Traffic and Transportation Engineering (English Edition),* vol. 8, no. 3, pp. 283-314, 2021. Crossref, https://doi.org/10.1016/j.jtte.2021.03.004

[8] Ning Li, Caijun Shi, Zuhua Zhang, Hao Wang and Yiwei Liu, "A Review on Mixture Design Methods for Geopolymer Concrete," *Composites Part B: Engineering,* vol. 178, pp. 107490, 2019. Crossref, https://doi.org/10.1016/j.compositesb.2019.107490

[9] Albitar M, Visintin P, Ali M.S.M and Dreehsler M, "Assessing Behaviour of Fresh and Hardened Geopolymer Concrete Mixed With Class-F Fly Ash," *KSCE Journal of Civil Engineering,* vol. 19, no. 5, pp. e1445, 2015. Crossref, https://doi.org/10.1007/s12205-014-1254-z

[10] Montes C, Gomez S.A, Khadka N and Allouche, E.N., "Statistical Software to Improve the Accuracy of Geopolymer Concrete Mix Design and Proportioning," *World of Coal Ash Conference*, Lexington, pp. 22-25, 2013.

[11] Nabila Shehata, O.A. Mohamed, Enas Taha Sayed, Mohammad Ali Abdelkareem and A.G. Olabi, "Geopolymer Concrete as Green Building Materials: Recent Applications, Sustainable Development and Circular Economy Potentials," *Science of the Total Environment*, vol. 836, pp. 155577, 2022. Crossref, https://doi.org/10.1016/j.scitotenv.2022.155577

[12] Y.H. Mugahed Amran, Rayed Alyousef, Hisham Alabduljabbar and Mohamed El-Zeadani, "Clean Production And Properties of Geopolymer Concrete, A Review," *Journal of Cleaner Production,* vol. 251, pp. 119679, 2020. Crossref, https://doi.org/10.1016/j.jclepro.2019.119679

[13] Luan, Chenchen, Shi, Xiaoshuang, Zhang, Kuanyu, Utashev, Nodir, Yang, Fuhua, Dai, Jinxin and Wang, Qingyuan, "A Mix Design Method of Fly Ash Geopolymer Concrete Based on Factors Analysis," *Construction and Building Materials*, vol. 272, pp. 121612, 2021. Crossref, https://doi.org/10.1016/j.conbuildmat.2020.121612

[14] Vemundla Ramesh and Koniki Srikanth, "Mechanical Properties and Mix Design of Geopolymer Concrete – A Review," *2nd International Conference on Design and Manufacturing Aspects for Sustainable Energy*, vol. 184, no. 6, pp. 1-5, 2020. Crossref, https://doi.org/10.1051/e3sconf/202018401091

[15] Hake, Sandeep, Awsarmal, Prashant and Damgir, R, "Durability Study on Fly Ash Based Geopolymer Concrete for Acidic Environment," *Global Journal of Material Science and Engineering*, pp. 13-18, 2019. Crossref, https://doi.org/10.37516/global.j.mater.sci.eng.2019.0076

[16] Rashidian-Dezfouli, Hassan, "Re: Is Cooling of Alkaline Activator for 24 Hours (For Alkali-Activated Binders) Scientifically Important?," 2019.

[17] Ramachandran, Anuradha, Venkataraman, Sreevidya, Venkatasubramani, R. and Rangan B, "Modified Guidelines for Geopolymer Concrete Mix Design Using Indian Standard," *Asian Journal of Civil Engineering*, vol. 13, no. 3, pp. 353-364, 2012.

[18] Abdullah, Mohd Mustafa Al Bakri, Kamarudin, H, Binhussain, Mohammed, Nizar, Khairul, Razak, Rafiza and Yahya, Zarina, "Comparison of Geopolymer Fly Ash and Ordinary Portland Cement to the Strength of Concrete," *Advanced Science Letters,* vol. 19, no. 12, pp. 3592-3595, 2013. Crossref, https://doi.org/10.1166/asl.2013.5187

[19] Patankar, Subhash, "Mix Design of Fly Ash Based Geopolymer Concrete," *SEC-14, Biannual ConferenceAt: IIT*, Delhi, 2014. Crossref, https://doi.org/10.1007/978-81-322-2187-6_123

[20] M.W. Ferdous, O. Kayali and A. Khennane, "A Detailed Procedure of Mix Design for Fly Ash Based Geopolymer Concrete Fourth Asia-Pacific Conference on FRP in Structures," *International Institute for FRP in Construction,* pp. 1-6, 2013.

[21] Ganesan Lavanya and Josephraj Jegan, "Durability Study on High Calcium Fly Ash Based Geopolymer Concrete Advances in Materials Sciences and Engineering," *Hindawi Publishing Corporation,* pp. 731056, 2015. Crossref, https://doi.org/10.1155/2015/731056

[22] M. Vaishnavi and M. K. Rao, "Durability of High Volume Fly Ash Concrete," *International Journal of Engineering Research and Technology*, vol. 3, no. 8, pp. 872-876, 2014. Crossref, https://doi.org/10.17577/IJERTV3IS080784

[23] Jyotirmoy Mishra, Shaswat Kumar Das, Saurabh Kumar Singh and Syed Mohammed Mustakim, "Development of Geopolymer Concrete for the Protection of Environment: A Greener Alternative to Cement," *SSRG International Journal of Civil Engineering*, vol. 6, no. 3, pp. 40-46, 2019. Crossref, https://doi.org/10.14445/23488352/IJCE-V6I3P106

[24] Chandani Tennakoon, Ahmad Shayan, Jay G Sanjayan and Aimin Xu, “Chloride Ingress and Steel Corrosion in Geopolymer Concrete Based on Long Term Tests,” *Materials & Design*, vol. 116, pp. 287-299, 2017. Crossref, https://doi.org/10.1016/j.matdes.2016.12.030

[25] Huang Ji Zhuang, Hai Yan Zhang and Hao Xu, “Resistance of Geopolymer Mortar to Acid and Chloride Attacks,” *Procedia Engineering*, vol. 210, pp. 126-131, 2017. Crossref, https://doi.org/10.1016/j.proeng.2017.11.057

[26] Shanmuganathan.N, Akbar Basha.S, Sheikibrahim.K and Mohammed Fahad A.S, "Ground Granulated Blast Furnace Slag (Ggbs or Ggbfs) and Fly Ash (Fa) in Concrete – A Study Report," *SSRG International Journal of Civil Engineering*, vol. 5, no. 3, pp. 13-17, 2018. Crossref, https://doi.org/10.14445/23488352/IJCE-V5I3P103

[27] T. Bakharev, J. G. Sanjayan and Y.-B Cheng, "Sulfate Attack on Alkali-Activated Slag Concrete," *Cement and Concrete Research*, vol. 32, no. 2, pp. 211-216, 2002. Crossref, https://doi.org/10.1016/S0008-8846(01)00659-7

[28] Ghanem, Gouda, Yehia, Sameh, Mohamed, Nehal and Helmy, Mohamed. "Effect of Sulphate Attack on Compressive Strength of Geopolymer Concrete," *International Journal of Scientific and Engineering Research*, vol. 13, no. 7, pp. 63-70, 2022.

[29] Bondar D, Lynsdale C.J, Milestone N.B, et al., “Sulfate Resistance of Alkali Activated Pozzolans,” *International Journal of Concrete Structures and Materials*, vol. 9, pp. 145-158, 2015. Crossref, https://doi.org/10.1007/s40069-014-0093-0

[30] Kumar R, Verma M and Dev N, “Investigation on the Effect of Seawater Condition, Sulphate Attack, Acid Attack, Freeze–Thaw Condition, and Wetting–Drying on the Geopolymer Concrete,” *Iranian Journal of Science and Technology Trans Civil Engineering*, vol. 46, pp. 2823-2853, 2022. Crossref, https://doi.org/10.1007/s40996-021-00767-9

[31] Bhutta, Aamer, Hussin, M, Ariffin, Mohd Azreen and Tahir, Mahmood, “Sulphate Resistance of Geopolymer Concrete Prepared from Blended Waste Fuel Ash,” *Journal of Materials in Civil Engineering*, vol. 26, no. 11, pp. 04014080, 2014. Crossref, https://doi.org/10.1061/(ASCE)MT.1943-5533.0001030

[32] “IS 10262, Recommended Guidelines for Concrete Mix Proportioning,” *Bureau of Indian Standards*, New Delhi, 2019.

[33] T. Bakharev, “Resistance of Geopolymer Materials to Acid Attack,” *Cement and Concrete Research*, vol. 35, no. 4, pp. 658-670, 2005. Crossref, https://doi.org/10.1016/j.cemconres.2004.06.005

[34] J J Ekaputri, H A Lie, C Fujiyama, M Shovitri, N H Alami and D H E Setiamarga, “The Effect of Alkali Concentration on Chloride Penetration in Geopolymer Concrete,” *IOP Conference Series: Materials Science and Engineering*, vol. 615, pp. 012114, 2019. Crossref, https://doi.org/10.1088/1757-899X/615/1/012114