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Experimental Study on Fresh, Hardened and Durability Characteristics of Sodium Silicate-Activated Geopolymer Concrete

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Abstract
Current study investigates the fresh, hardened and durability characteristics of geopolymer concrete (GC) developed using sodium silicate (Na_2SiO_3) as an alkaline-activator (A-A) for M25, M40 and M70 grades. Low calcium fly ash (LFA) and ground granulated blast furnace slag (GGBS) were used as alkaline binders. The fresh properties were evaluated using the slump test, while the hardened properties were assessed through the Ultrasonic Pulse Velocity (UPV) test and compressive strength (CS) test. Durability characteristics were investigated using the water absorption test, accelerated carbonation test, acid attack test with 5% HCl and 5% H_2SO4 and fire resistance test at 400°C, 600°C and 700°C for 1 hour duration of heating. The slump values for M25, M40 and M70 grade GC were 110mm, 110mm and 120mm respectively. UPV results indicated that M25 and M40 grade GC fell under the medium to good quality concrete category, while M70 grade GC was classified as excellent quality concrete. The CS, weight lossand strength loss factors were evaluated for each grade of GC exposed to acid attack and fire resistance tests. The results demonstrate the potential of Na_2SiO_3based GC as a sustainable alternative to the combination of sodium hydroxide (NaOH) and Na_2SiO_3 as an A-A concrete.
Keywords: - Geopolymer concrete, Sodium silicate, Fresh properties, Hardened properties, Durability characteristics, Fire resistance

1. Introduction

As the population grows, the creation of infrastructure becomes increasingly crucial. It has a big impact on cement usage. The cement sector contributes significantly to CO_2 emissions worldwide, making up roughly 6–8% of total emissions[1,2]. Thus, one of the main causes of global warming is the manufacture of cement. Massive amounts of raw materials from finite natural resources are consumed at a high pace throughout the process of production, which causes their decline. The procedure used to make cement is very wasteful in terms of resource effectiveness. Waste rates throughout the phases of clinker production, cement grinding and raw material preparation, were found to be, 74.12%, 78.89% and 63.31% respectively, in a cement plant investigation[3].

In the building industry, GC is showing promise as a substitute for traditional cement concrete (CC), providing a number of benefits[4,5]. By using fly ash, a byproduct of burning coal, in place of cement, GC lowers expenses and carbon dioxide emissions[6,7]. Aluminosilicate materials and alkaline activator solutions undergo a polycondensation reaction to create this novel material[8–10].According to studies, GC's mechanical characteristics are better than those of CC. As an example, GC has a 20% to 30% better flexural strength than CC[7,11].

Furthermore, it has been discovered that GC exhibits less creep and shrinkage over the long term than CC[10,12–14]. It is important to note, though, that GC typically has a Poisson's ratio and lower elasticity modulus than CC[15,16]. GC is positioned to become more and more significant in sustainable building practices as research continues to move from chemistry to applications in engineering and manufacturing for commercial use[17–19].

The alkali activation of LFA and GGBS with NaOH and Na_2SiO_3 has been widely documented in the literature. When an alkaline (i.e., NaOH and Na_2SiO_3) solution is used to activate the binder such as GGBS, the concrete becomes less workable and hardens more quickly.In certain literature, Na_2SiO_3 is employed as an alkaline activator to get around this difficulty[20,21]. Vikas Gugulothu and Gunneswara Rao (2020)[21], have used neutral Na_2SiO_3 as an alkaline activator to develop GGBS-based GC. Workability tests have been performed at different GGBS quantities (400, 500 and 600 kg/m3) and alkaline solution-to-binder ratios of 0.55,0.6,0.65,0.7,0.75 and 0.8, respectively, to investigate the GCs setting time. According to the results, the CS range for these binder contents was 60–80 MPa. These mixes had a workability range of 80 to 110 mm. The current study's findings demonstrate that A-Aconcretes can be activated using a neutral Na_2SiO_3 solution under ambient curing, making them more appropriate for use in the building sector.

The durability features of GC have been the subject of numerous investigations, with a focus on several different factors, including performance in severe temperatures, carbonation, resistance to acid attack and chloride penetration. According to research, the GC frequently exhibits better durability qualities than the CC[17–19]. For example, GC has proven to be more resistant to chloride penetration, sulphate assault, and acid corrosion. The calcium level of the mixture, which is essential to the durability mechanism, is one of the important factors for the long-term durability of GC. Furthermore, GC's microstructure—which is distinguished by a dense matrix and less porosity—contributes to its improved durability qualities[7,11].

Additionally, the mix design, curing circumstances, and the kind of precursor materials utilized to generate GC can all have an impact on durability characteristics[15,16]. The standardization of mix design processes, examining the impact of various precursor materials and activators on durability, and creating thorough durability evaluation methods for GC should be the main objectives of future research[17–19]. This will help GC become more widely used as a long-lasting, sustainable building material and cost-effective.

Therefore, in the present study, the M25, M40 and M70 grade GC is developed using Na_2SiO_3 as an alkaline activator. The Fresh characteristics, hardened characteristics such as CStest and UPV test and durability characteristics such as Water absorption test, carbonation test, acid attack test for HCl and H_2SO_4, fire resistance test at 400°C, 600°C and 700°Crespectively.

2. Experimental Program

2.1. Materials

2.1.1. Alkaline Binders

GC is synthesized using LFA and GGBS. From the Ramagundam Thermal Power Plant in Telangana, India, the LFA was purchased. This FA is categorized as LFA in accordance with IS 3812 [22] and its mass percentage of CaO does not exceed 10%. From the JSW manufacturers provided the GGBS is used for the present study. The chemical characteristics and dosage of the materials can affect the performance of GC. Table 1 displays the chemical composition of the GGBS and LFA utilized in GC mixtures.

Table 1. Fly Ash and GGBS Chemical Composition

Sl. No.	Composition	GGBS (% by mass)	Fly ash (% by mass)
1	SiO_2	32.47	58.19
2	Al_2O_3	14.45	39.02
3	CaO	40.74	0.90
4	MgO	6.99	0.28
5	K_2O	0.29	0.88
6	Na_2O	0.16	0.88

2.1.2. Aggregates

In this investigation, river sand that complies with IS 383 standards was utilized as the fine aggregate. The aggregate's maximum grain size falls between 10 and 20 mm is used as coarse aggregate for the development of GC. The essential tests are executed based on IS 383-2016 [23] for river sand and coarse aggregates, such as Specific gravity (G), Bulk density($\boldsymbol{\rho}$) and Fineness Modulus(m). In the case of river sand, the values are 2.64, 1.71 kg/m3 and 3.52. Whereas for coarse aggregate the values are 2.72, 1.55 kg/m3 and 2.57 respectively.

2.1.3. Alkaline Activator

The $Na_2SiO_3$is used as an alkaline solution to activate the geo-polymerization process in GC. The approximate molar mass of Na_2SiO_3 used for the present studyis 122.06 g/mol. For the development of M25, M40 and M70 grades GC in ambient curing. The Grade-A53 Na_2SiO_3 solution, also known as liquid sodium silicate, is purchased from a nearby distributor and utilized as an alkaline solution.

2.2. Mix Proportions

To develop M25, M40 and M70 grade GC in ambient curing several trials are conducted by using Na_2SiO_3 as an alkaline solution. Table 2 depicts the mix proportion of GC for M25, M40 and M70 grade GC. The methodology to study the durability properties of M25, M40 and M70 grade GC by using Na_2SiO_3 as the alkaline solution is shown in Figure 1.

Table 2 Mix proportion

Grade	**GGBS (kg/m^3)**	**Fly Ash (kg/m^3)**	**20mm Coarse aggregate (kg/m^3)**	**10mm Coarse aggregate (kg/m^3)**	**River Sand (kg/m^3)**	**Liquid (litre/m^3)**
M25	165	165	620	500	750	198
M40	270	180	555	455	670	270
M70	480	120	380	310	450	360

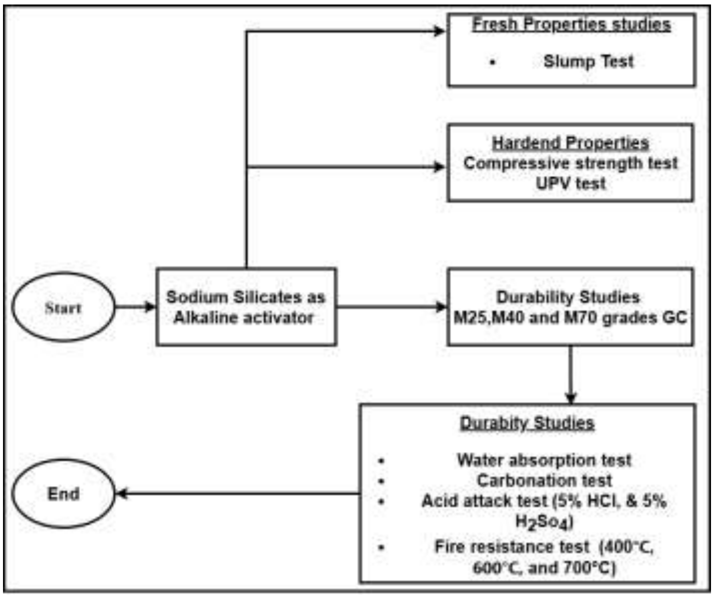

Figure 1. Methodology

2.3. Casting and Curing

The M25, M40 and M70 grade-based GC is prepared with Na_2SiO_3 as an alkaline activator, which was cast using the same technique as conventional concrete. First, in a pan mixer, the dry aggregates such as coarse and fine aggregates are mixed for 2 to 3 minutes. Then alkaline binders such as LFA and GGBS were added to the pan mixer and the mixture was mixed for 2 to 3 more minutes. Furthermore, alkaline activators such as Na_2SiO_3 are added to the dry ingredients and mixed for 2 to 4 minutes to get good homogeneity of the fresh mix. The fresh mix was poured into cube molds having dimensions 150x150x150 mm for every three layers and compaction was done for each layer using

20mm tamped by giving 35 to 40 blows. The casting of cubes, casted cubes and cubes kept at ambient temperature for a period of28, 60 and 90 days is revealed in Figure 2.

Figure 2. (a) Casting of cubes (b) Casted Cubes (c) Cubes kept for ambient curing

3. Experimental investigation

3.1. Fresh characteristics

To determine the fresh characteristics of alkaline activated i.e., Na_2SiO_3 based M25, M40 and M70 based GC the test such as slump test is conducted as per IS 1199-2004 guideline. The workability of every sample i.e. M25, M40 and M70 grade-based mix is evaluated.

3.2. Hardened characteristics

3.2.1. Ultrasonic Pulse Velocity test

UPV testM25, M40 and M70 GC specimens were subjected to a UPV test. A 54kHz point ultrasonic head and a Unipan 543 digital device in compliance with IS 516 (Part5/Sec1), 2018. The UPV test was performed on M25, M40 and M70 GC cubes using the direct transmission method in this investigation. Figure3 depicts the UPV test configuration used in the investigation.

Figure 3.UPV test

3.2.2. Compressive Strength Test

In accordance with IS: 516 2004, the CSof M25, M40 and M70 GC was ascertained. A compression testing machine (CTM) with a 2000 kN was used to test the cube specimens with a 150 x 150 x 150 mm dimension, as shown in Figure 4. The mean of three specimens was used to evaluateCSvalues.

Figure 4. Compressive Testing Machine

3.3. Durability characteristics

3.3.1. Water Absorption Test (150mm)

The 150 x 150 x 150 mm cubes manufactured of M25, M40 and M70 grade-based GC were used for the water absorption test as shown in Figure 5. The GC cubes were weighed as W_1 after 28 days of ambient curing. Following a 24-hour immersion in water, the samples' weight was determined to be W_2. Equation (1) was used to determine the percentage of water absorption.

Percentage of absorption (%) = $\left(\frac{W2-W1}{W2}\right)$ x 100(1)

Figure 5. Cubes kept in water for water absorption test

3.3.2. AcceleratedCarbonation Test

To evaluate the accelerated carbonation test, 150 x 150 x 150 mm dimension cube samples were used. The next day after casting, the samples were kept in ambient curing for 28 days. The cube sample is then cut from the center of the cube. The carbonation depth was observed by applying a 1% phenolphthalein in an alcohol solution to the top layer of the divided concrete specimens of M25, M40 and M70 grade GC.

3.3.3. Acid Attack test

All M25, M40 and M70 grade-based GC combinations' 150 ×150 ×150 mm cube specimens were immersed in a 5% HCl and 5% H_2SO_4 solution for 30, 60 and 90 days, as shown in Figures 6 and 7, respectively. To maintain consistency during the test time, the HCl and H_2SO_4solutions were frequently replaced and mixed. The samples were weighed on a dry surface soon after the specimens were removed from the diluted acid fluid.

For every GC graded M25, M40 and M70, the weight loss factor (WFL)and CS loss factor (CLF)were calculated.By comparing the weight of the concrete samples before and after their being treated with acid, the WFLwas calculated. At each predetermined time, the WLF of the concrete samples was evaluated using equation (2). Whereas W_1 and W_2 are the weight before and after exposure to an acid attack.

$$WLF\ (\%) = \left(\frac{W1-w2}{W1}\right) x\ 100 \qquad (2)$$

Similarly, a change in the specimen's weight caused by significant exposure to acid for 30, 60 and 90 days results in a decrease in CS, which indicates the CLF. The strength of concrete samples that had been cured under ambientcuring for 28 days was contrasted with the residual strength of GC samples following exposure to an acidic environment. The CLF percentage was determined using equation (3).

$$CLF\ (\%) = \left(\frac{Residual\ Strength}{Initial\ orginal\ Strength}\right) x\ 100 \qquad (3)$$

Figure 6. Cubes kept in 5% HCl

Figure 7. Cubes kept in 5% H_2SO_4

3.3.4. Fire Resistance

In the current investigation a cube of 100 x 100 x 100 mm dimensions is used for the M25, M40 and M70 grade-based GC specimens and they are exposed to temperatures up to 700 °C. Using a high-temperature Tilting furnace having a crucible capacity of 5kg and maximum heating temperature of up to 1200°C, as shown in Figure 8. and Figure 9 illustrates the specific steps involved in producing heat and cooling at high temperatures. GC samples were exposed to 200°C, 400°C and 700 °C to examine their mechanical properties. After removal from the furnace, the samples were allowed to cool for 24 hours at room temperature prior to examination.

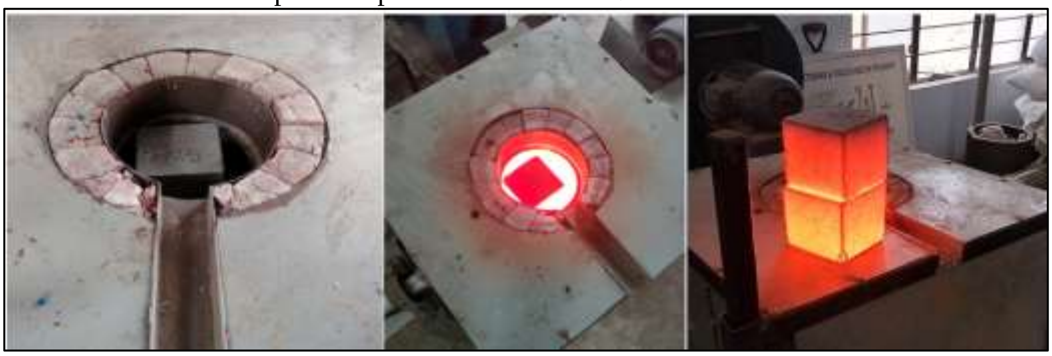

Figure 8. Tilting furnace and appearance of heated specimens

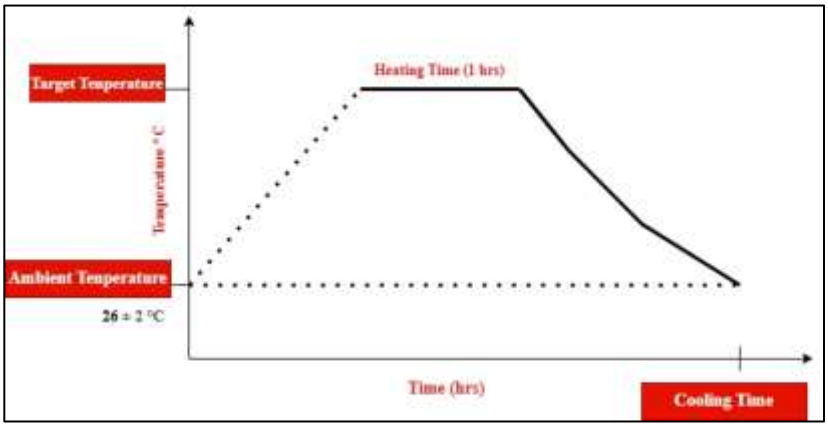

Figure 9. Heating and Cooling Process of the cube specimens

4. Results and Discussion

4.1. Fresh characteristic

The fresh characteristics of GC are necessary to study for homogeneity and ease of utilization of concrete for casting by performing workability studies. The Workability of GC is evaluated by the slump test for GC for M25, M40 and M70 grades to measure this rheological characteristic of the fresh state of Na_2SiO_3 alkaline activated-based GC. The Slump values of M25, M40 and M70 grade-based GC are 110mm, 110mm and 120mm respectively. The slump test results of M25, M40 and M70 grade GC are illustrated in Figure 10.

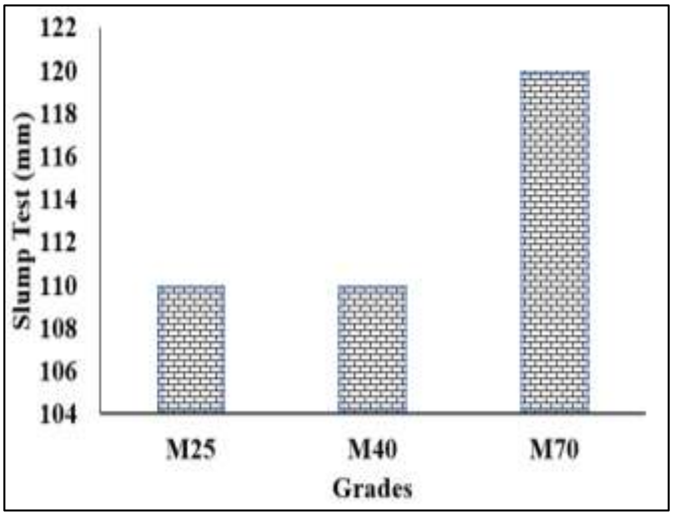

Figure 10. Slump values of the M25, M40 and M70 grades

4.2. Hardened characteristic

4.2.1. Ultrasonic Pulse Velocity test

According to IS: 516 (Part 5/ Sec 1) –2018, the UPV values are classified into four categories based on the quality of concrete as shown in Table 3.

Table 3. Classification of UPV values as per IS: 516 (Part 5/ Sec 1) –2018

S.NO	Categories	UPV value (km/s)
1	Excellent	4-5
2	Good	3.5-4.5
3	Medium	3-3.5
4	Doubtful	2-3

The UPV values of alkaline activated i.e., Na_2SiO_3-based M25, M40 and M70 grades are shown in Figure 11. From Figure 11, it was observed that, in the case of 28 days of ambient curing, the M25 and M40 grades GC fall under the medium category and good category concrete, while M70 grade GC falls under the excellent category concrete. Whereas in the case of 60 and 90 days ambient curing the M25 and M40 grades GC fall under the good category concrete, while M70 grade GC falls under the excellent category concrete. The change in UPV value for 60 and 90 days of curing over time is due to the continuous progress of the geopolymerization process which leads to the larger and more interconnected gel matrix being formed, such as C-S-H and N-A-S-H gels. The microstructure is enhanced by this prolonged polymerization, giving the concrete greater density and strength.

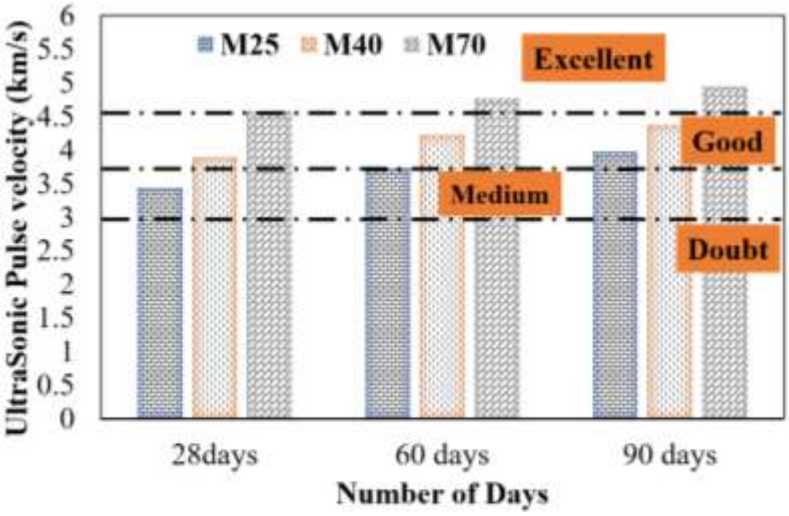

Figure 11. UPV values of the M25, M40 and M70 grades GC at 28,60 and 90days of ambient curing

4.3. Compressive strength (unheated)

The cube CSvalues of M25, M40 and M70 grade GCs for 28, 60 and 90 days of ambient curing are shown in Figure 12. For M25 grade alkaline activated Na_2SiO_3 based GC the achieved CSvalues at 28 days, 60 days and 90 days are 28.3,29.6 and 30.5 MPa, respectively. For the M40 grade, the CSvalues are 51.7, 52.5 and 53.2 MPa. For M70 grade GC, the CSvalues are 72.8, 73.8 and 74.4 MPa, respectively. It was observed from the results that a marginal variation of CS values after 60 days and 90 days of ambient curing compared to 28 days of CSvalues.

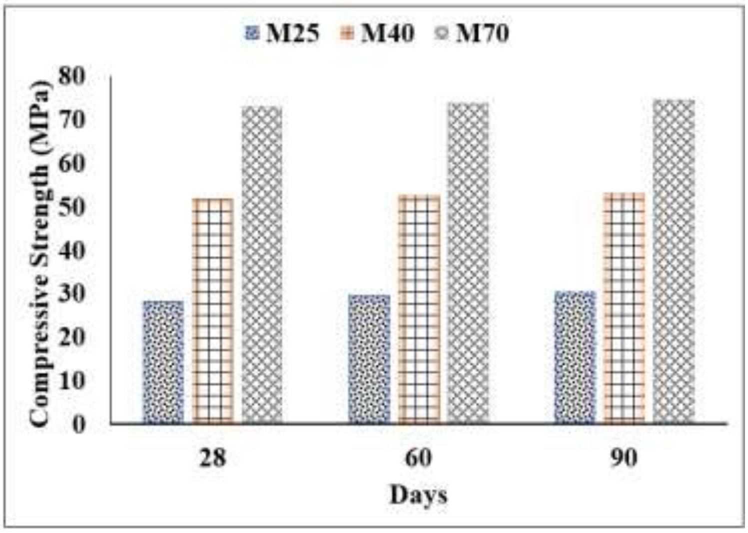

Figure 12. CSvalues of the M25, M40 and M70 grades GC at 28,60 and 90days of ambient curing

4.4. Water absorption test

The water absorption findings for the M25, M40 and M70 grade GC are shown in Table 4. For M25, M40 and M70 grade GC, the measured water absorption percentages are 4.67%, 2.75% and 2.10%, respectively. As the Grade of GC increases the water absorption capacity is gradually decreasing. According to these findings, the M70 grade's water absorption ratio is noticeably lower than that of the M25 and M40 Grade GC. The amorphous structure of the particles employed in GC effectively fills the spaces and gaps that usually form in lower grades of M25 and M40 Grade GC, which explains the decreased water absorption value in M70 GC. This results in a denser microstructure, which raises the material's total density while simultaneously reducing porosity.

Table 4. Water absorption values of the M25, M40 and M70 grades of GC at 28days

Grades	Initial Weight	Weight	% Absorption	Average % Absorption
	8.41	8.73	3.67	
	8.38	8.88	5.63	4.67
M25	8.49	8.91	4.71	
	8.42	8.66	2.77	
	8.37	8.67	3.46	2.75
M40	8.28	8.45	2.01	
	8.33	8.51	2.12	
	8.36	8.54	2.11	2.10
M70	8.43	8.61	2.09	

4.5. Carbonation Test

Figures 13 and 14 display the carbonation depth and images of the phenolphthalein indicator values for accelerated carbonation of M25, M40 andM70 grade GCs. The average values of 15–20 measurements were taken for the carbonation depths as shown in Figure. 13. The results showed that the carbonation depths for M25, M40 andM70 grades of GC are 11 mm, 8 mm and 5.7 mm, respectively. It was observed from the result that as the grade of GCs increases, carbonation depth gradually decreases. The reason for the decrease in carbonation depth by increasing the grade of GC is explained by previous literatures [7,24]. According to Samuel et al. (2023) [24] state that the presence of Ca-rich phases like C-(A)-S-H or C-(N)-A-S-H led to a significant effect of GGBS content on mortar qualities. These phases serve as buffer materials which is essential for increasing carbonation resistance and encouraging microstructure densification.

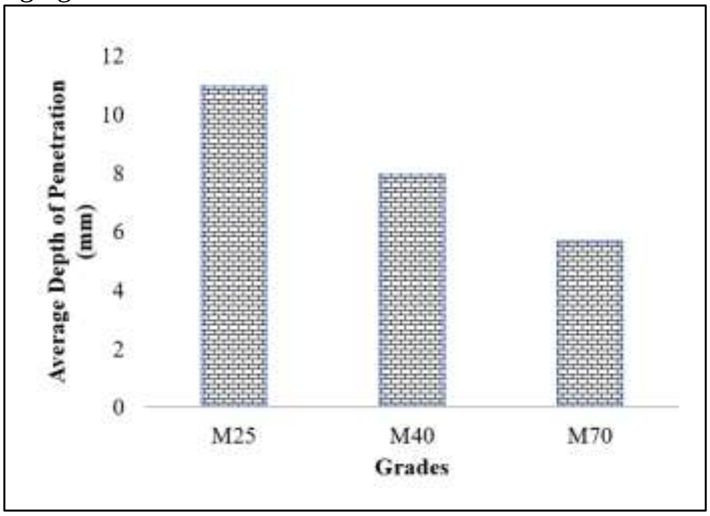

Figure 13. Carbonation depth of M25, M40 and M70 grades of GC samples after 28days of ambient curing

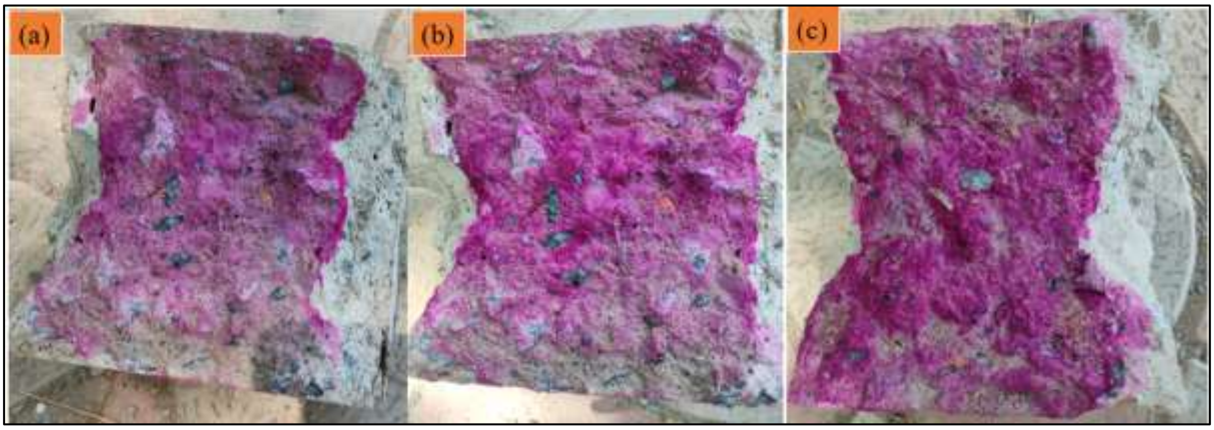

Figure 14. Mmeasurement of carbonated depth ofGC samples for (a) M25, (b) M40 and(c) M70 grades

4.6. Acid Attack test

4.6.1. Physical Observation

Figures 15 and 16 show the influence of a 5 % HCl and 5% H_2SO_4 solution on M25, M40 and M70 grade GC following a 28, 60 and 90-day exposure period. Both the acid solution shows evidence of changes in color, edge distortion and surface cracks in the M25, M40 and M70 grades of GC samples. Compared to the 5% HCl solution, the 5%H_2SO_4 solution shows more amount of change in color and surface cracks. In GC, H_2SO_4 combines with calcium-based substances such as calcium hydroxide to create gypsum. Gypsum is less stable and has the potential to crystallize, which might cause discoloration and change the GC's appearance[15].

Figure 15. Physical appearance of M25, M40 and M70 grades GC samples after exposed to 5%HCl

Figure 16. Physical appearance of M25, M40 and M70 grades GC samples after exposed to 5%H_2SO_4

4.6.2. Weight Loss Factor

Tables 5 and 6 show the weight changes and WFL results for the M25, M40 and M70 grade GC after 30, 60 and 90 days of exposure in 5%HCl and 5% H_2SO_4 solutions, respectively. After concrete samples were immersed in 5% HCl and 5% H_2SO_4 for 30, 60 and 90 days, the specimens' weight changes were noted. The average WFL for the M25, M40 and M70 grade GC, immersion in 30 days of 5%HCl and 5%H_2SO_4 solutions is in a range of 4.5 to 7.9%. For 60 days the average WFL for both 5%HCl and 5%H_2SO_4 solutions in M25, M40 and M70 grade GC is 8% to 9.5% respectively. Furtherly for 90 days, the average WFL is 10.1% to 12.5% respectively.It was observed from the results that as the number of days of acid exposure increases (i.e., 30, 60 and 90 days) the WFL gradually increases. Among both acids, 5% H_2SO_4 shows more WFL than the 5% HCl acid solution.

WFL in the GC specimens may result from the production of gypsum in concrete after interacting with sulfate from the H_2SO_4 solution, which is less stable and can crystallize. [15].

Table 5. Weight loss of cube specimen after exposure to 5%HCl acid for 3, 60 and 90 days

	30 days				**60 Days**				**90 Days**			
Grades	**Initial Weight of cube specimen**	**Weight loss after HCl attack**	**WLF (%)**	**Avg WLF (%)**	**Initial Weight of cube specimen**	**Weight loss after HCl attack**	**WLF (%)**	**Avg WLF (%)**	**Initial Weight of cube specimen**	**Weight loss after HCl attack**	**WLF (%)**	**Avg WLF (%)**
	8.32	7.93	4.7		8.23	7.46	9.4		8.3	7.24	12.8	
	8.21	7.85	4.4	5.5	8.38	7.51	10.4	9.5	8.33	7.19	13.7	12.4
M25	8.41	7.78	7.5		8.28	7.56	8.7		8.39	7.49	10.7	
	8.44	8.04	4.7		8.48	7.49	11.7		8.41	7.28	13.4	
	8.42	8.12	3.6	5.2	8.49	7.87	7.3	9.3	8.34	7.47	10.4	11.5
M40	8.46	7.85	7.2		8.39	7.64	8.9		8.47	7.56	10.7	
	8.32	7.99	4.0		8.27	7.83	5.3		8.37	7.38	11.8	
	8.29	7.82	5.7	4.5	8.34	7.63	8.5	8.8	8.33	7.06	15.2	11.9
M70	8.35	8.03	3.8		8.32	7.27	12.6		8.28	7.56	8.7	

Table 6. Weight loss of cube specimen after exposer to H2SO4 acid for 3, 60 and 90 days

	30 days				**60 Days**				**90 days**			
Grades	**Initial Weight of cube specimen**	**Weight loss after H_2SO_4 attack**	**WLF (%)**	**Avg WLF (%)**	**Initial Weight of cube specimen**	**Weight loss after H_2SO_4attack**	**WLF (%)**	**Avg WLF (%)**	**Initial Weight of cube specimen**	**Weight loss after H_2SO_4attack**	**WLF (%)**	**Avg WLF (%)**
	8.39	7.89	6.0		8.29	7.69	7.2		8.45	7.39	12.5	
	8.43	7.74	8.2	7.7	8.35	7.54	9.7	8.0	8.41	7.41	11.9	11.8
M25	8.31	7.56	9.0		8.34	7.75	7.1		8.43	7.5	11.0	
	8.49	7.98	6.0	6.8	8.48	7.84	7.5	8.7	8.29	7.27	12.3	12.5
M40	8.41	7.88	6.3		8.38	7.68	8.4		8.32	7.38	11.3	

	8.47	7.79	8.0		8.32	7.48	10.1		8.37	7.21	13.9	
	8.32	7.74	7.0		8.22	7.56	8.0		8.31	7.43	10.6	
	8.29	7.59	8.4	7.9	8.31	7.59	8.7	7.9	8.31	7.58	8.8	10.1
M70	8.35	7.67	8.1		8.27	7.69	7.0		8.24	7.33	11.0	

4.6.3. Compressive Strength Loss Factor

Tables 7 and 8 show the changes in CSand CFL results for the M25, M40 and M70 grade GC after 30, 60 and 90 days of exposure in 5%HCl and 5% H_2SO_4 solutions, respectively. After concrete samples were immersed in 5% HCl and 5% H_2SO_4 for 30, 60 and 90 days, the specimens' changes in CSwere noted.The average CFL for the M25, M40 and M70 grade GC, immersion in 30,60 and 90 days of 5%HCl solutions is in a range of 12.3 to 34%. In the case of the 5% H_2SO_4 solution, the average CLF is 22.4% to 34.4%.It was observed from the results that as the number of days of acid exposure increases (i.e., 30, 60 and 90 days) the CFL gradually increases. Among both acids, 5% H_2SO_4 shows more CFL than the 5% HCl acid solution. Due to the loss of weight in the cube specimen and forming voids in the inside of the concrete this leads to a reduction of strength.

Table 7. Loss of CS after exposure to HCl acid for 30, 60 and 90 days

	30 days				**60 Days**				**90 Days**			
rades	**Ultimate Load (kN)**	**Initial CS(MPa)**	**CLF (%)**	**AvgCLF (%)**	**Load**	**Strength**	**CLF (%)**	**AvgCLF (%)**	**Load**	**Strength**	**CLF (%)**	**AvgCLF (%)**
	532	23.6	16.5		517	23.0	22.4		417	18.5	39.2	
	580	25.8	8.9	12.6	548	24.4	17.7	22.4	435	19.3	36.6	34.0
25	557	24.8	12.5		485	21.6	27.2		507	22.5	26.1	
	1014	45.1	12.8		961	42.7	18.6		849	37.7	29.1	
	1023	45.5	12.1	12.3	904	40.2	23.5	21.1	768	34.1	34.0	32.5
40	1025	45.6	11.9		930	41.3	21.3		762	33.9	34.5	
	1470	65.3	10.3		1356	60.3	18.3		1049	46.6	37.3	
	1420	63.1	13.3	12.8	1234	54.8	25.7	22.9	1210	53.8	26.1	31.9
70	1395	62.0	14.8		1253	55.7	24.5		1112	49.4	32.1	

ble 8. Loss of CS after exposure to H2SO4 acid for 30, 60 and 90 days

	30 Days				**60 Days**				**90 Days**			
rades	**Ultimate Load (kN)**	**Initial CS (MPa)**	**CLF(%)**	**Avg CLF(%)**	**Ultimate Load (kN)**	**Initial CS (MPa)**	**CLF(%)**	**Avg CLF(%)**	**Ultimate Load (kN)**	**Initial CS (MPa)**	**CLF(%)**	**Avg CLF(**
	492	21.9	22.7		441	19.6	33.8		436	19.4	36.5	
	512	22.8	19.6	22.4	532	23.6	20.1	26.1	504	22.4	26.6	31.5
25	478	21.2	24.9		503	22.4	24.5		470	20.9	31.5	
	946	42.0	18.7		928	41.2	21.4		829	36.8	30.7	
	910	40.4	21.8	21.4	846	37.6	28.4	25.5	754	33.5	37.0	34.4
40	887	39.4	23.7		867	38.5	26.6		772	34.3	35.5	
	1334	59.3	18.6		1224	54.4	26.3		1069	47.5	36.1	
	1386	61.6	15.4	18.3	1292	57.4	22.2	24.5	1188	52.8	29.0	32.3
70	1295	57.6	20.9		1244	55.3	25.1		1140	50.7	31.9	

4.7. Fire Resistance

4.7.1. Weight Loss

The experimental findings on the weight reduction of M25, M40 and M70 grade GCs after exposure to different temperatures of 400◦C, 600◦C and 700◦C are shown in Figure. 16. Figure. 16 illustrates as the temperature increases the weight loss is gradually increasing. At 400◦C of temperature exposure, the weight loss for M25, M40 and M70 grade GCs is 10.29%, 8.65% and 7.83%, respectively. For 600 ◦C of temperature heating the percentage of weight loss for M25, M40 and M70 grade GCs is 13.56%, 10.5% and 9.88%, respectively. Whereas in the case of 700 ◦C, the percentage of weight loss is 14.52%, 12.54% and 11.78% respectively. The M70 grade shows less amount of weight loss compared to the M25 and M40 grades, this may be due to the strong bonding between the geopolymer gels[7].

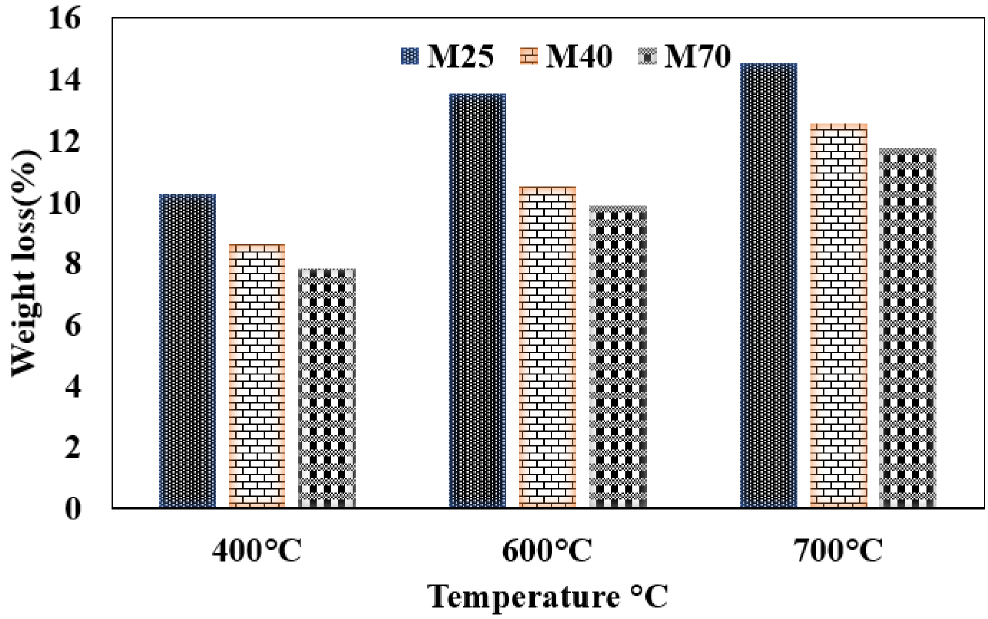

Figure 16. Weight loss values of M25, M40 and M70 grades after being exposed to a temperature of 400˚C, 600˚C and 700˚C

4.7.2. Influence of fire on CS of GPC for various grades

Figure 17 shows the residual CSfor each of the tested combinations' M25, M40 and M70 grades. Figure 17, also shows the correlation between residual CS and exposure temperatures of 400°C, 600°C and 700°C.Comparing M25, M40 and M70 grade GCs to unexposed cube specimens, the residual CS is determined. For M25 grade GC, at 400°C, 600°C and 700°C the residual CS is 17.73 MPa,8.2MPa and 7.35MPa, respectively. For M40 grade GC, the values are 35.12 MPa, 18.85MPa and 16.5 MPa. Furtherly for M70 grade GC, the residual CS is 52.9 MPa, 29.85 MPa and26.2 MPa.

Interestingly, when the specimens were subjected to 400 ◦C, the rate of strength loss was lower compared to 600 and 700°C. As was noted, all mixes showed a general decrease in CSas the temperature increased, especially from room temperature to 700 ◦C. The two main processes that cause strength degradation at high temperatures are mass loss from moisture evaporation and deformation caused by heat. When the specimens are heated, the moisture—which includes both free and chemically bound water—moves to the outside and evaporates. The interior microstructure of the samples is severely harmed by this evaporation process, which also contributes to the CS drop [15].

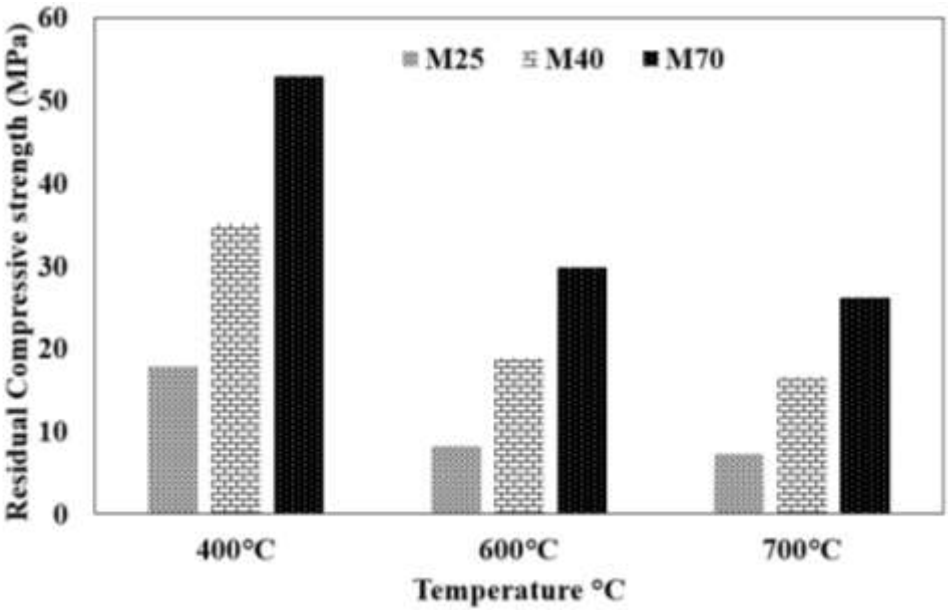

Figure 17. Residual CS values of M25, M40 and M70 grades after being exposed to a temperature of 400°C, 600°C and 700°C

5. Conclusion

This study investigates the fresh, hardened and durability characteristics of M25, M40 and M70 grade GC developed using Na_2SiO_3 as an alkaline activator. FA and GGBS were used as alkaline binders. The fresh properties were evaluated using the slump test, while the hardened properties were assessed through the UPV test and CStest. Durability characteristics were investigated using the water absorption test, accelerated carbonation test, acid attack test with HCl and H_2SO_4 and fire resistance test at 400°C, 600°C and 700°C.

- The results showed that the slump values for M25, M40 and M70 grade GC were 110mm, 110mm and 120mm, respectively.
- UPV results indicated that M25 and M40 grade GC fell under the medium to good quality concrete category, while M70 grade GC was classified as excellent quality concrete.
- The CS, weight loss and strength loss factors were evaluated for each grade of GC exposed to acid attack and fire resistance tests, with M70 grade GC showing better performance compared to M25 and M40 grades.

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