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Research Article

## Study on strength and porosity of alkali activated geopolymer based pervious concrete

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### Abstract

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The construction sector that contributes significantly to economic and social growth also has environmental issues, generating 30-40% of the global carbon dioxide emissions. Regular concrete employed in pavement prevents groundwater recharge and enhances flood hazards and soil erosion. Pervious concrete employed in pavement is a sustainable option by permitting water penetration. Geopolymer concrete, a novel material, is defined by its distinct chemical composition employing industrial waste products, providing economic sustainability, low energy requirement, workability, and environmental sustainability with low carbon emission. The current research discusses geopolymer pervious concrete employing a 70% fly ash and 30% Ground Granulated Blast Furnace Slag mixture, with a fly ash-alone version. This research will identify the compressive strength and split tensile strength of geopolymer pervious concrete and investigate the infiltration capacity and acid resistance of porous concrete in terms of various aggregate sizes and optimize the mix design for sustainable pavement application.

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## 1. Introduction

Advances in technology and specialized machinery have facilitated easy production of larger amounts of cement. The increase and quick production of cement results in massive carbon emissions. Warming of the planet via CO<sub>2</sub> emissions is a serious global issue, and cement production accounts for approximately 10% of global emissions alone [1]. The construction sector, being a large consumer of energy and resources, also produces emissions such as dust, nitrogen oxide, and sulphur dioxide, resulting in environmental degradation [2]. In order to minimize this effect, the sector must use sustainable materials and energy efficient alternatives.

Geopolymer pervious concrete offers a possible solution by blending the green advantages of geopolymers and the groundwater recharge capacity of pervious concrete for pavements [3]. With the utilization of industrial by-products such as fly ash and ground granulated blast-furnace slag (GGBS), the process has a major carbon footprint reduction, waste minimization, and improved urban water management through water permeability, storm water runoff attenuation, and groundwater recharge [4].

### 1.1 Literature Review

The Pervious concrete is a sustainable material that optimizes permeability and strength, perfect for stormwater management and flood mitigation in urban areas. Mix design, type of aggregate, binder

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composition, and curing conditions influence pervious concrete behavior. Several methods have been attempted in recent years to improve its mechanical and hydraulic performance, such as substituting geopolymer binders for traditional cement.

Pervious concrete is a useful contribution to sustainable urban planning through natural aquifer recharge. Coupling geopolymer technology with pervious concrete achieves sustainable construction objectives through the minimization of traditional cement with improved environmental performance. Though geopolymer and pervious concrete have been investigated separately, a considerable gap exists in identifying their potential when used together. Utilization of alkali-activated materials or geopolymers as binders presents an environmentally friendly alternative to Portland cement with improved durability and mechanical performance. Fly ash and slag geopolymers are dependent on alkali activators NaOH and  $\text{Na}_2\text{SiO}_3$ , which influence strength and porosity [6]. The balance between porosity and strength is decided by mix design, aggregate size, and curing conditions [7,28]. Structural integrity with maintained permeability is ensured through optimum optimization [9]. Limitations include maintaining high compressive strength without sacrificing porosity [10] and optimizing aggregate grading for mechanical performance [11]. Environmental conditions like freeze-thaw cycles influence durability [12], and recycled materials make it more sustainable [13]. Interdependence of strength and permeability requires an optimum mix design [7].

The pervious concrete infiltration capacity depends on surface slope and aggregate content. The research discovered that a higher surface slope decreases infiltration while the use of recycled aggregates enhanced permeability by 50% in a mix based on ACI 522 [14]. In the same manner, suggested simplified mix design using Proctor and Roller compaction, demonstrating its capability to manage density and porosity [15]. Geopolymer pervious concrete, produced from alkali-activated fly ash and GGBS, has also been found to be promising. It was proved that 30% replacement of GGBS activated with a 12M sodium silicate and NaOH solution gave the best strength and durability [16]. Further the strength increases with increase in molarity till 12M after which gain in strength decreases [47]. The proportion of the mix is also important in maintaining porosity and compressive strength. It was stated that 1:4 mix ratio resulted in increased strength but reduced porosity, while 1:7 mix was porous but weak [16, 17].

Aggregate size and mix proportion selection have a significant influence on strength and infiltration rates. Strength of 26.9 MPa was achieved with 6.9 mm/sec permeability from 12.5–16 mm aggregates as per IS 10262:2009 [18]. It was also reported that bigger aggregates (4.75–19.5 mm) enhanced strength (10–26 MPa) and permeability (0.4–1.26 cm/sec) [19]. The addition of supplementary cementitious materials (SCMs) such as GGBS and silica fume has also improved pervious concrete performance. A study by [20] noted that the substitution of 25% OPC with GGBFS and 25% silica fume resulted in the maximum strength of 5.86 MPa. Likewise, a mix was produced for geopolymer pervious concrete (GPPC) with GGBS and attained around 20 MPa strength with a 0.3 activator-to-GGBS ratio. The mechanical properties of pervious concrete can also be enhanced by fiber reinforcement and optimal water-to-cement ratios. A study discovered that fibers added 32%-50% strength, whereas the water-cement ratio (0.27–0.33) greatly impacted mechanical properties [22]. Moreover, curing at high temperatures has proven to increase strength. It was found fly ash/GGBS geopolymer concrete cured at 80°C had a compressive strength of 44.84 MPa [23].

Research proposed a simplified mix design using Proctor and Roller compaction, showing its effectiveness in controlling density and porosity [24]. Geopolymer-based pervious concrete, made using alkali-activated fly ash and GGBS, has shown promising results. As demonstrated in a study that 30% GGBS replacement activated with a 12M sodium silicate and NaOH solution provided optimal strength and durability.

Extensive research has explored geopolymers as a cement alternative and pervious concrete for environmental benefits such as groundwater replenishment, heat island mitigation, and noise reduction. Studies confirm that OPC serves as a viable binder for pervious concrete but with an inverse relationship between strength and porosity. A few studies achieved desired strength by replacing 50% OPC with GGBS but overlooked aggregate proportioning. A few other studies examined inclined pervious concrete without considering compaction effects on porosity and infiltration. Additionally,

while confirming the strength-porosity trade off, studies failed to test resistance to acid or sulphate attacks, crucial for chemically aggressive environments.

## 2. Methodology

This study focuses on optimizing pervious geopolymer concrete through aggregate proportioning and geopolymer variations. It evaluates compressive strength, split tensile strength, infiltration, porosity, and chemical resistance. Previous research on binary geopolymer concrete (fly ash & GGBS) highlighted durability improvements influenced by alkaline solution molarity and curing conditions. This study aims to bridge that gap by analysing environmental benefits, structural performance, and groundwater recharge potential. Using industrial by-products like fly ash and GGBS, it promotes sustainable construction. A 70% fly ash – 30% GGBS mix is adopted for pervious geopolymer concrete. A comparative study with fly ash based geopolymer concrete assesses porosity, strength, and durability. Samples undergo 28-day sunlight curing, followed by chemical resistance tests with 5% sodium sulphate & sulphuric acid after 56 days. The research investigates strength and porosity in alkali-activated materials or geopolymer pervious concrete. It emphasizes binder composition, curing, and aggregate selection for sustainable applications. Fig .1 shows flow chart of the study

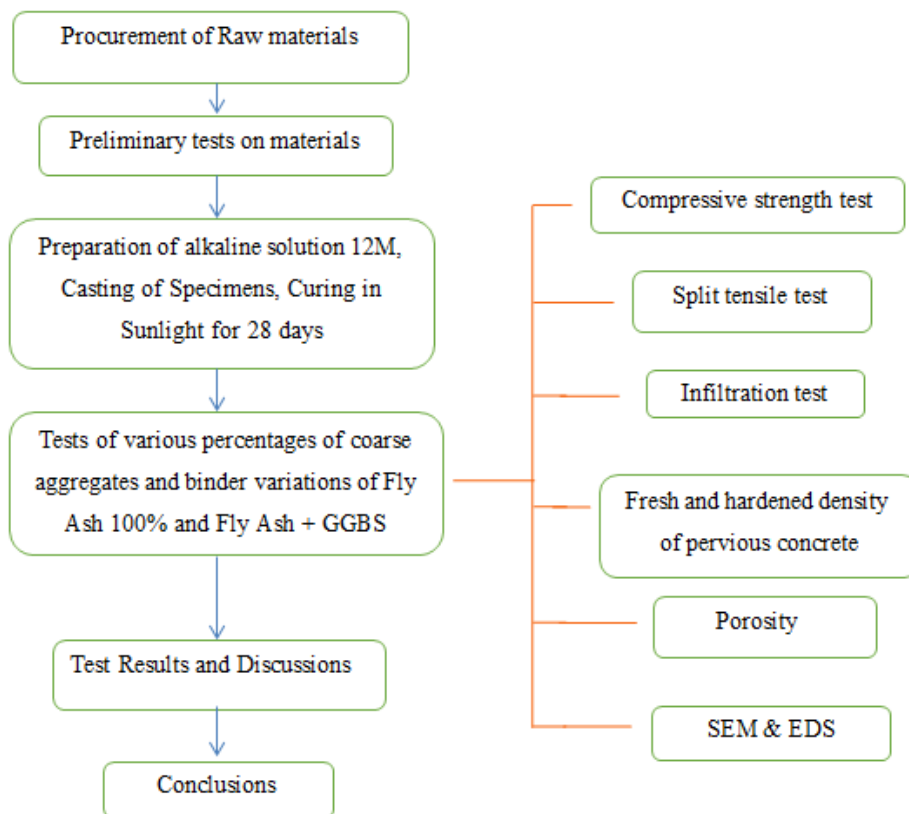


Fig. 1. Flow chart of the experimental program

Tests were carried out on the test samples in two stages. In the first stage, initial tests were carried out to determine material properties like specific gravity, density, and fineness of the aggregates and binders. During the second stage, coarse aggregate proportion was changed between 0% to 30% with increments of 10%. Two different compositions of binders were utilized, which included FA100-GG0 (100% Fly Ash, 0% GGBS) and FA70-GG30 (70% Fly Ash, 30% GGBS). The number of cubes, cylinders, and slabs prepared for testing their strength and durability totalled 48, 16, and 16, respectively, and all these specimens were exposed to sunlight while being cured.

### 2.1 Materials Used

In this study Fly ash and GGBS were used as precursors where variation in flyash percentage was 100 and 70, GGBS varied as 0 and 30. Molarity of alkaline activator solution was kept constant for all the mixes at 12. NaOH and Na<sub>2</sub>SiO<sub>3</sub> were used in preparation of alkaline solution which was done a day

prior to mixing. Fly ash used in this study contains ~55–60% SiO<sub>2</sub>, ~25–30% Al<sub>2</sub>O<sub>3</sub>, and <10% CaO, classifying it as low-calcium fly ash (ASTM Class F). GGBS is rich in CaO (~35–40%) with latent hydraulic properties that enhance C–A–S–H gel formation

## 2.2 Mix Proportions

Mixes considered in the study were designated as shown in table 1 which consists of total 8 mixes and for the same mixes proportion of material are mentioned in table 2

Table 1. Mixes considered in the study

Mix Designation	Fly Ash %	GGBS%	CCA % (12.5 mm – 10 mm)	FCA % (10 mm – 4.75 mm)
FA100CCA100	100	-	100	-
FA70CCA100	70	30	100	-
FA100CCA90	100	-	90	10
FA70CCA90	70	30	90	10
FA100CCA80	100	-	80	20
FA70CCA80	70	30	80	20
FA100CCA70	100	-	70	30
FA70CCA70	70	30	70	30

Here, CCA: Coarser Coarse Aggregate, FCA: Finer Coarse Aggregate

Table 2. Mix proportion of the mixes considered in the study

Mix Designation	Fly Ash (kg/m <sup>3</sup> )	GGBS (kg/m <sup>3</sup> )	CCA (kg/m <sup>3</sup> )	FCA (kg/m <sup>3</sup> )	NaOH (kg/m <sup>3</sup> )	Na <sub>2</sub> SiO <sub>3</sub> (kg/m <sup>3</sup> )
FA100CCA100	411	0	1958	0	10.07	25.18
FA70CCA100	288	123	1958	0	10.07	25.18
FA100CCA90	411	0	1762	196	10.07	25.18
FA70CCA90	288	123	1762	196	10.07	25.18
FA100CCA80	411	0	1566	392	10.07	25.18
FA70CCA80	288	123	1566	392	10.07	25.18
FA100CCA70	411	0	1372	586	10.07	25.18
FA70CCA70	288	123	1372	586	10.07	25.18

## 2.3 Preparation and Curing of Specimens

Geopolymer concrete is produced using traditional methods similar to Portland cement concrete. In this study, manual mixing was performed in the laboratory following safety protocols. The process began with dry mixing of fly ash and GGBS for 4–6 minutes, followed by the addition of two sizes of coarse aggregates (4.75–10 mm and 10–12.5 mm). The alkaline solution (sodium hydroxide and sodium silicate) was prepared a day in advance and then mixed with dry ingredients for 10 minutes to ensure uniform distribution. A SNF (Sulphonated Naphthalene Formaldehyde) based superplasticizer was added to improve workability. The concrete was cast into cubes (150 mm), cylinders (150 mm × 300 mm), and slabs (300 mm × 300 mm × 50mm) for infiltration test as shown in Figure 2, with the number of specimens based on testing requirements after 28 days of curing. The curing of geopolymer concrete depends on temperature, requiring at least 30°C for optimal strength. In tropical climates, this is achieved through ambient conditions where specimens were cured under direct sunlight in Hyderabad, India, during the months of April–June 2024, with ambient temperatures ranging from 30°C to 44°C. Test specimens shown in figure 3(a) were de-molded after 24 hours and cured in direct sunlight at 30–44°C as shown in figure 3(b).



Fig. 2. Rings sealed to the surface of slab specimen as per ASTM C1701 (2)



(a)



(b)

Fig. 3. (a) Samples prepared for various tests; (b) Curing of samples under sunlight

## 2.4 Tests Conducted

### 2.4.1 Compressive Strength and Split Tensile Strength

Compressive strength was evaluated by testing three cubes per mix after 28, 56 & 90 days of sunlight curing as shown in Figure 4. A total of 48 geopolymer pervious concrete cubes were tested following IS 516 :1959[6] standards. The split tensile strength of cylinders of 8 different mixes was tested at 28 days after sunlight curing



Fig. 4. Compressive test on Cube Specimens

### 2.4.2 Infiltration Test on Slab Specimen

The porosity of cylindrical specimens and cores was measured after 28 days of sunlight curing. Specimens were weighed, submerged in water for 30 minutes, and then reweighed to determine porosity. The infiltration rate was assessed following ASTM C1688/C1688M-14a (26). The infiltration rate, crucial for stormwater management, was measured using ASTM C1701 (27) on 7-day-old slab specimens. A 300 mm × 50 mm plastic infiltration ring was fixed with plumber's putty at the slab's center as shown in Figure 5. A pre-wetting test used 3.60 kg of water, timed from impact until no free water remained. Since the elapsed time exceeded 30 seconds, the standard test (18 kg of water) was repeated three times, and the average time was recorded to determine the infiltration rate.



Fig. 5. Infiltration test of Pervious concrete slab

### 2.4.3 Infiltration Rate of a Cylindrical Specimen

For the casted cylindrical specimens, an infiltration test was performed using shrink-wrap to seal the sides of the specimens as shown in figure 6 and 7. Two lines of 10 and 15 mm were also marked above the pervious concrete surface, inside the shrink-wrap, to maintain the water head during the test. The quantity of water was adapted from the recommendation of ASTM C1701 [2] to the diameter of 100 mm corresponding to the specimen.



Fig. 6. Using shrink wrap to wrap specimen for infiltration test



Fig. 7. Infiltration test of Pervious concrete cylinder

The pre-wetting was also performed with 1.2 kg of water. If the elapsed time in the pre-wetting was less than 30 seconds, a total of 6 kg of water was used in the test. The test was then repeated three times to obtain an average time to determine the infiltration rate and compared to the results obtained for the slab. This test was performed at the age of 28 days. In both cases (slab and cylindrical specimens), infiltration rate ( $I$ ) in mm/h was determined according to the following equation (1):

$$I = \frac{k * M}{T * D^2} \quad (1)$$

where M: mass of infiltrated water in kg, D: diameter of infiltration in mm, t: recorded time related to the water infiltration in s, and K: factor needed to convert the recorded data, with a value of 4583666000 in SI units.

#### 2.4.4 Scanning Electron Microscopy and Energy Dispersive Spectroscopy

Scanning Electron Microscopy (SEM) is essential in materials science, providing high-resolution images to analyze microstructure and surface characteristics. In this research, SEM helps examine grain boundaries, phases, and defects, offering insights into structural properties. Its energy-dispersive X-ray spectroscopy (EDS) capability enables elemental analysis, identifying and quantifying elements in the material. EDS enhances understanding of material composition, variations, and elemental distribution. Together, SEM and EDS play a crucial role in studying structural transformations and validating research findings.

#### 2.4.5 Testing Procedure for SEM (Scanning Electron Microscopy)

For SEM analysis, a representative concrete sample is prepared by cutting a small section and mounting it on a stub. If necessary, a conductive coating like gold or carbon is applied to prevent charging during imaging. The sample is then placed in the SEM chamber under vacuum, and electron beam settings are adjusted based on its characteristics as shown in Figure 8. High-resolution images are captured at various magnifications to analyze surface topography, porosity, and microstructural features. If equipped with an EDS detector, elemental analysis can be performed simultaneously to map the material composition.

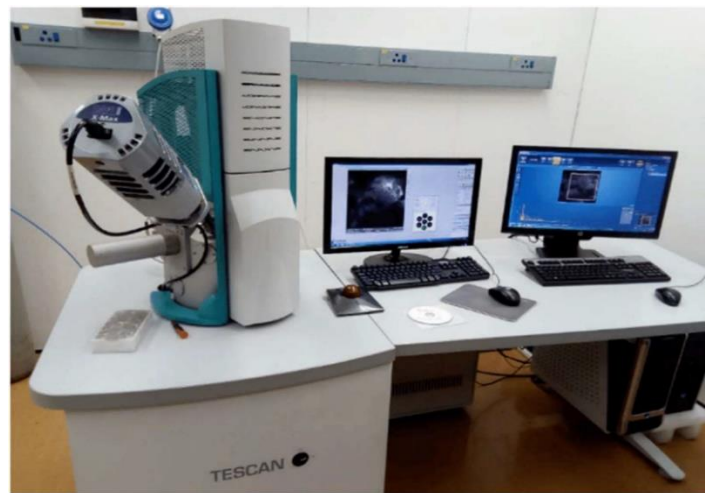


Fig. 8. SEM and EDS scanning machine

#### 2.4.6 Fresh and Hardened Density of Concrete

Fresh and hardened density tests assess concrete quality, ensuring the mix meets design specifications and compaction requirements. Fresh density was determined using cylindrical specimens compacted with a proctor hammer and measured immediately after casting. Calculations followed ASTM C1688 (18) for fresh density and ASTM C1754 (27) for hardened density. Hardened density was measured by weighing specimens and dividing by their volumes at 27 days, just before split tensile testing.

#### 2.4.7 Percentage Porosity

The porosity of cast cylindrical specimens and cores were calculated as per eq(2) according to ASTM C1754 [27]. This procedure was carried out after 28 days of sunlight curing. As per the code ASTM C1754 [27] after measuring the mass of the specimens it was submerged in water for 30 minutes. After 30 min the specimens were removed from water and their submerged mass was measured.

$$Porosity = \left[ 1 - \frac{M_d - M_s}{\rho_w * V} \right] \times 100 \tag{2}$$

Where,  $M_d$ : dry mass of the specimen in g,  $M_s$ : submerged mass of the specimen in g,  $\rho_w$ : density of water g/cm<sup>3</sup>, and  $V$ : volume of the specimen in cm<sup>3</sup>.

### 3. Results and Discussions

#### 3.1 Compressive Strength and Split Tensile Strength

Compressive strength and split tensile are the most important tests by which the concrete quality can be assessed and the results are tabulated in table 3 for the mixes considered in the study.

Table 3. Compressive Strength and Split Tensile Strength values of mixes considered in the study

Mix Designation	Compressive Strength 28 days	Compressive Strength 56 days	Compressive Strength 90 days	Split Tensile Strength
FA100CCA100	7.55 ± 0.25	8.00 ± 0.28	8.22 ± 0.30	3.11 ± 0.15
FA70CCA100	14.22 ± 0.40	14.66 ± 0.45	14.88 ± 0.47	5.77 ± 0.25
FA100CCA90	8.44 ± 0.28	9.33 ± 0.30	9.55 ± 0.32	3.11 ± 0.12
FA70CCA90	15.33 ± 0.42	15.55 ± 0.46	15.77 ± 0.48	6.66 ± 0.27
FA100CCA80	8.88 ± 0.26	9.55 ± 0.31	9.55 ± 0.31	3.55 ± 0.14
FA70CCA80	16.22 ± 0.45	16.66 ± 0.48	16.88 ± 0.50	6.66 ± 0.27
FA100CCA70	9.33 ± 0.27	9.77 ± 0.33	10.00 ± 0.35	4.00 ± 0.18
FA70CCA70	17.33 ± 0.48	18.22 ± 0.52	18.44 ± 0.55	7.11 ± 0.30

From the above results of Table 3 it can be seen that the with increase in fine coarse aggregate content the strength of the mix increases as seen for 10%,20% and 30% fine coarse aggregate. The fly ash content also has an impact on the strength of concrete where it has shown better performance with lower content i.e., at 70%. To sum up, the FA70 with CCA70 outperformed every other mix in the study as higher CaO promotes C-A-S-H formation (3 and 8).

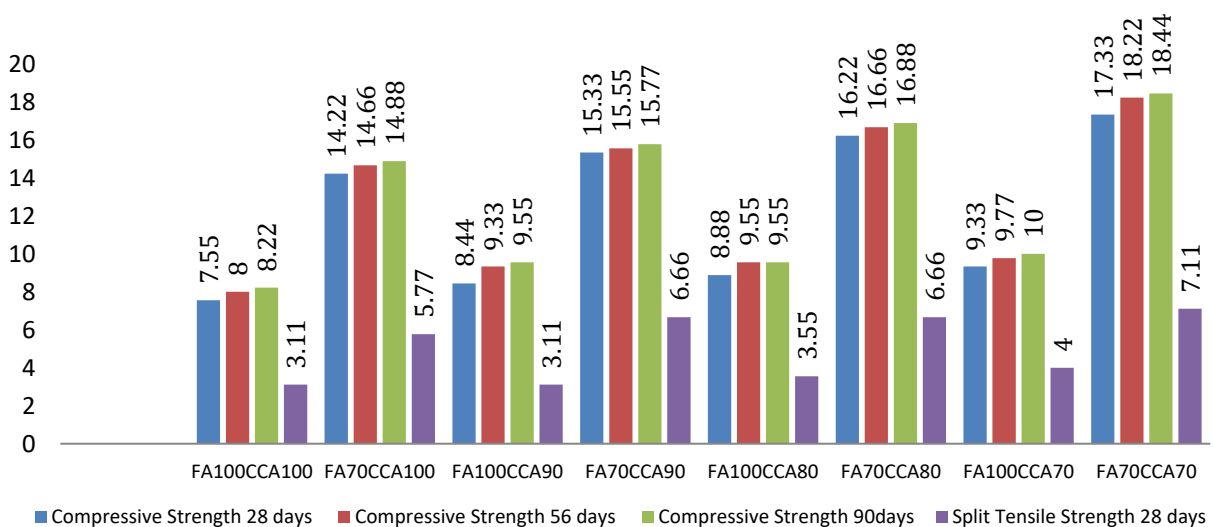


Fig. 9. Compressive strength and tensile strength of mixes

#### 3.2 Fresh vs Hardened Density Vs Porosity for Cast Specimens

The fresh density was determined for the casted cylindrical specimens. A proctor hammer was used for compaction of the specimen and its mass was measured immediately after casting. As per ASTM C1688 [26] the fresh density was calculated and as per ASTM C1754 [27], hardened density was calculated.

The weight of specimen was measured and then divided by their respective volumes at the age of 27 days (1 day before split tensile tests).

Table 4. Fresh and hardened density of mixes considered in the study

Mix number	Fresh density kg/m <sup>3</sup>	Hardened density kg/m <sup>3</sup>	Porosity %
FA100CCA100	1905.30	1898.52	28
FA70CCA100	1988.50	1947.06	26
FA100CCA90	1990.40	1965.97	24
FA70CCA90	1992.34	1965.97	25
FA100CCA80	2021.80	1998.1	22
FA70CCA80	2088.40	2024	22
FA100CCA70	2088.10	2024.5	18
FA70CCA70	2205.20	2168.24	17

In the above Table 4, hardened densities of all the mixes were calculated it was observed that similar to the fresh density of the sample's, maximum hardened density was achieved in Mix 8 with 70% fly ash and 30% GGBS with 70% CCA and 30% FCA. The average fresh density of geopolymer pervious concrete was found to be 2035 kg/m<sup>3</sup> and the average hardened density of pervious concrete was found to be 1985.62 kg/m<sup>3</sup>. A graph shown in figure 10 was also plotted which shows a negative correlation between hardened density and porosity have an R<sup>2</sup> value of 0.952.

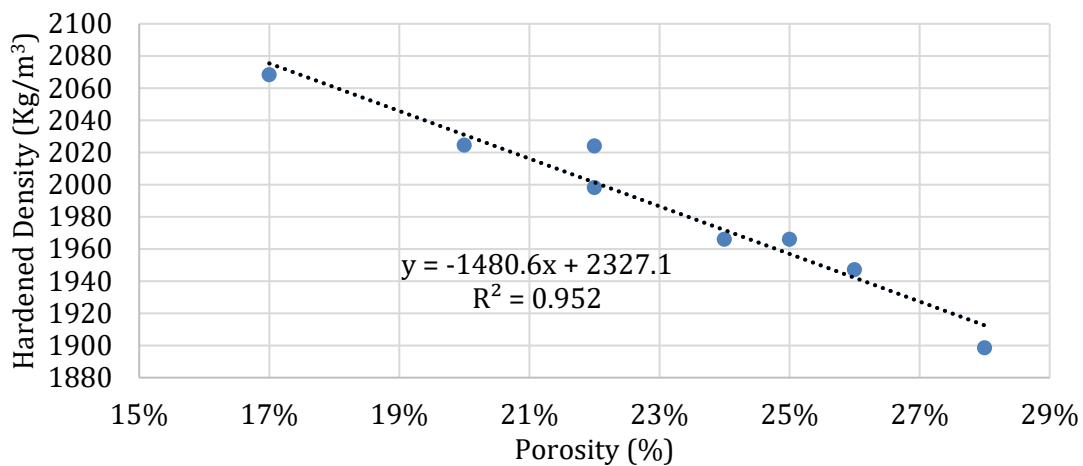


Fig. 10. Hardened density vs porosity of pervious concrete

### 3.3 Infiltration Rate vs Porosity

The infiltration rate of pervious concrete is closely related to its porosity. In pervious concrete, porosity refers to the volume percentage of voids within the material, and these voids are intentionally designed to allow water to pass through. Proper compaction during installation is crucial to achieving the desired porosity. Inadequate compaction can lead to reduced infiltration rates. The porosity of pervious concrete is a key factor influencing its infiltration rate. Higher porosity provides more pathways for water to infiltrate through the material, aligning with the purpose of pervious concrete in managing stormwater runoff and promoting sustainable drainage solutions. The results for infiltration rate are tabulated in Table 5.

The infiltration rate decreases as aggregate size decreases. Larger aggregates (10–12.5 mm) create larger interconnected voids, enhancing permeability, while finer aggregates (4.75–10 mm) fill pores, reducing infiltration. This aligns with (50) who reported infiltration of 0.4–1.26 cm/s for aggregates between 4.75–19.5 mm.

Above plot i.e., Figure 11 shows the relationship between infiltration rate of the slab (mm/min) and porosity (%). The trend is positive, indicating that as porosity levels increase so does the infiltration rate. This means that the more porous the slabs, the quicker water infiltrates.

Table 5. Infiltration rate vs Porosity of mixes considered in the study

Mix design	Time taken (sec)	Infiltration rate of Slab (mm/min)	Infiltration rate of Cylinder (mm/min)	Porosity %
FA100CCA100	49	62.3	214.44	28
FA70CCA100	53	57.65	194.01	26
FA100CCA90	62	49	185.19	24
FA70CCA90	60	50.9	145.51	25
FA100CCA80	86	35.53	169.76	22
FA70CCA80	92	33.21	1334.46	22
FA100CCA70	105	29.1	135.81	18
FA70CCA70	120	25.46	116.41	17

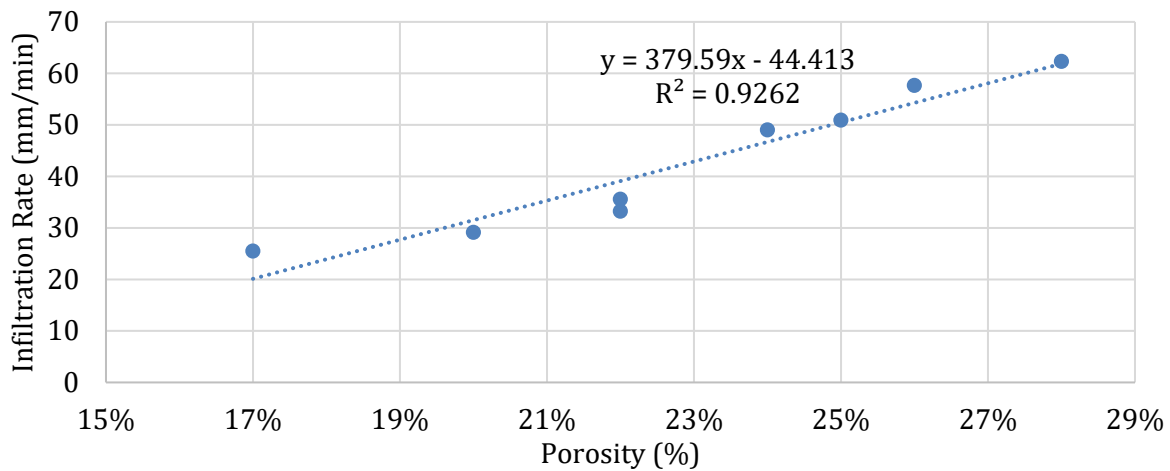


Fig. 11. Slab infiltration rate vs porosity of pervious concrete

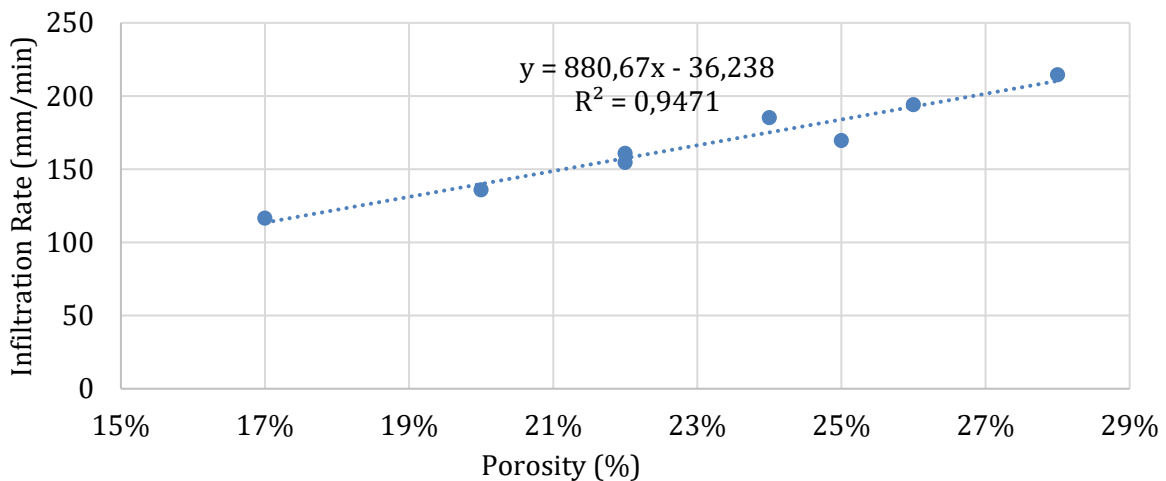


Fig. 12. Cylinder infiltration rate vs porosity of pervious concrete

A  $R^2$  value of 0.926, indicates a high correlation, which reveals that 92.62% of the variation in infiltration rate is explained by variations in porosity. This is beneficial in real world applications, where increased porosity is beneficial to increase water permeability for stormwater management. From the above figures 11 and 12 it can be observed that there is a positive correlation with increase in the porosity the infiltration rate also increases for both slab and cylindrical specimens. The figure 12 depicts the correlation between infiltration rate (mm/min) and porosity (%) for cylindrical samples. The trend is a strong positive correlation, which means that as the porosity rises, the infiltration rate also increases.

A  $R^2$  value of 0.9471, shows that there is an extremely strong relationship, with 94.71% of infiltration rate variation accounted for by variations in porosity. The infiltration rates in cylindrical samples are significantly greater than those in slabs (as evident from Figure 11), which may be due to differences in geometry, compaction, or boundary effects

### 3.4 Chemical Attack

The sample made using geopolymers based pervious concrete was submerged in a 5% diluted solution of sulphuric acid. To maintain the solution's concentration, it was mixed and monitored on a regular basis. At 56 days, the specimens were tested under compression testing machine as per IS 516 1959 [35] and the results are shown in Table 6. In the above table it can be observed that samples of both binders were affected by acid when submerged in it for 56 days. When compared to samples cured for 56 days and samples in acid for 56 days there was around 15% decrease in compressive strength. Similar trend could be observed in the weights of the samples before and after attack decreased by around 4%.

Table 6. Compressive strength and weight loss of pervious concrete before and after acid attack

Mix number	Average compressive strength 56 days before attack (MPa)	Average compressive strength 56 days after attack (MPa)	Percentage decrease in strength (%)	Average weight before attack (kgs)	Average weight after attack (kgs)	Percentage decrease in weight (%)
Mix1	8.00	6.88	14%	7.04	6.76	3.97%
Mix2	14.66	12.44	15.14%	7.10	6.78	4.5%
Mix3	8.88	7.55	14.97%	7.28	6.99	3.98%
Mix4	15.55	13.11	15.69%	7.32	7.04	3.82%
Mix5	9.33	8.00	14.25%	7.61	7.35	3.41%
Mix6	16.66	14.44	13.32%	7.65	7.33	4.18%
Mix7	9.77	8.44	13.61%	7.92	7.62	3.78%
Mix8	18.22	15.55	14.65%	7.95	7.63	4.02%

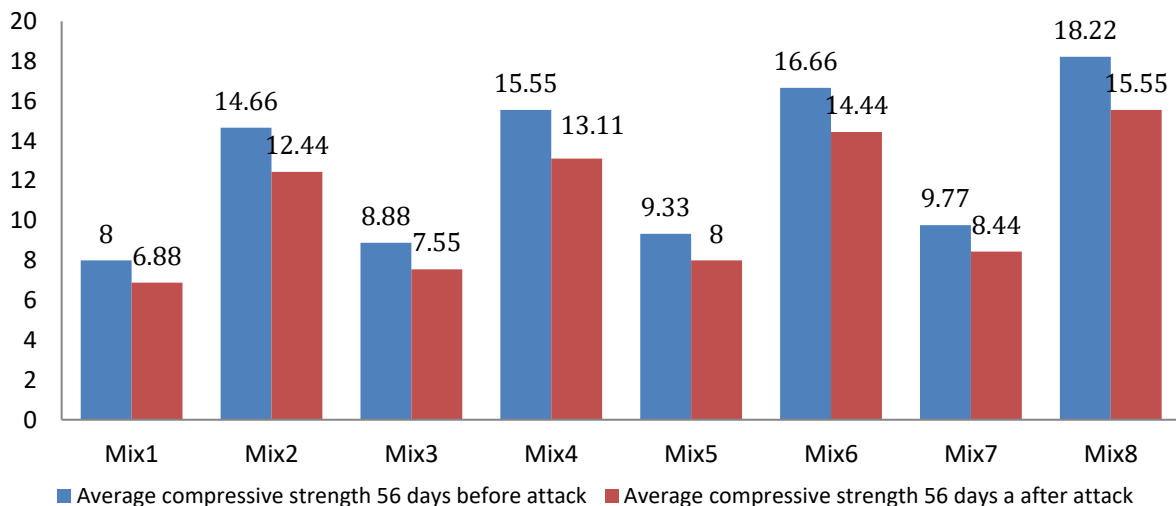


Fig. 13. Compressive Strength (N/Sq.mm) Before and after attack

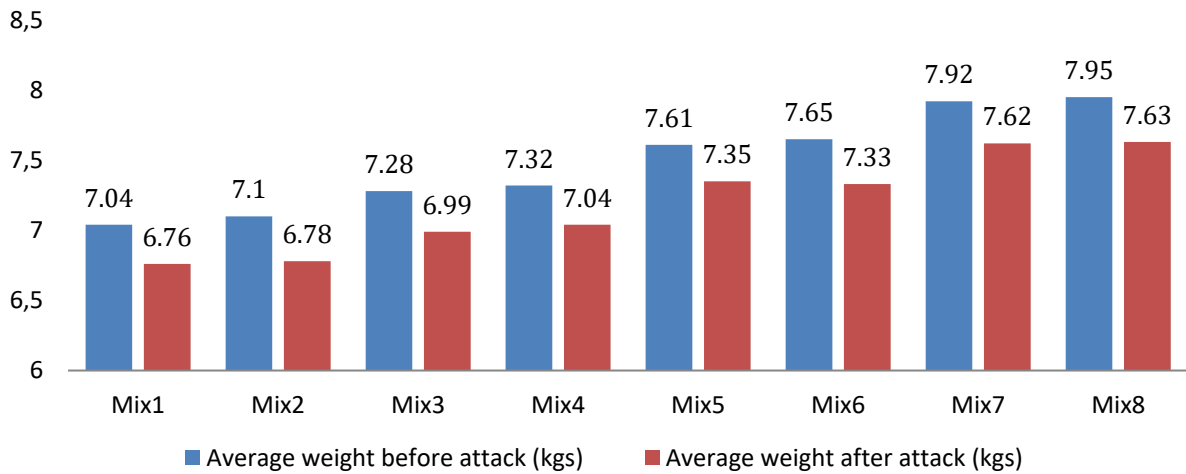


Fig. 14. Weight Loss in kgs before and after attack

### 3.5 Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy (EDX)

Scanning electron microscopy was done on cube specimens to have better understanding of the morphology of the samples, the hydration of binder used in the mix, the formation of concrete gel and to check if there are pores or cracks in the previous concrete. Following are the images captured after the test shown from fig 15 to 24.

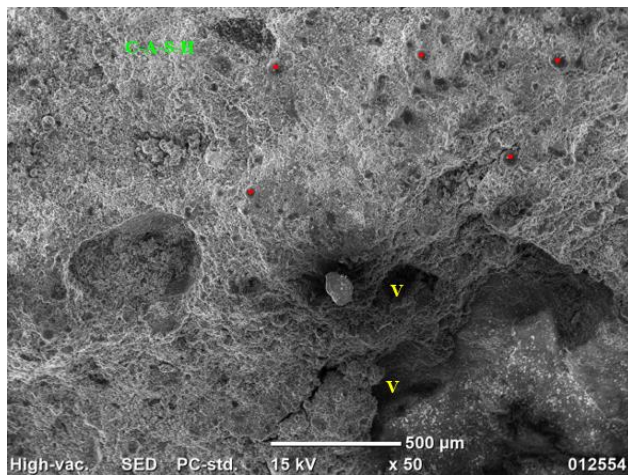


Fig. 15. SEM 500µ image of FA100CCA90

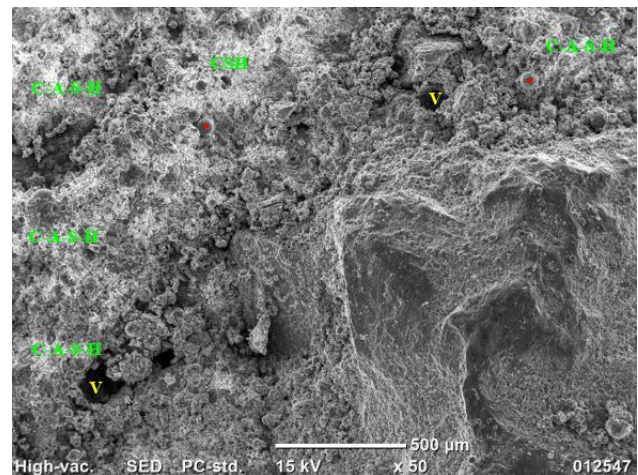


Fig. 16. SEM 500µ image of FA70CCA90

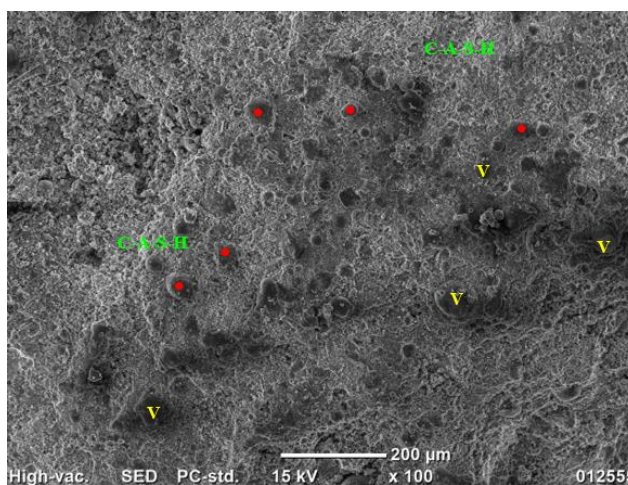


Fig. 17. SEM 200µ image of FA100CCA90

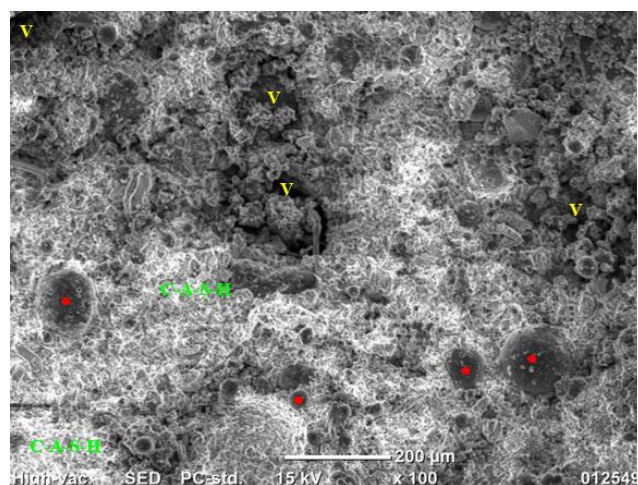


Fig.18. SEM 200µ image of FA70CCA90

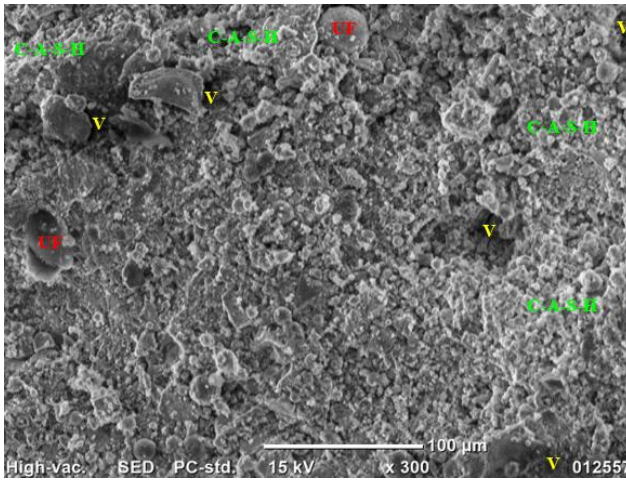


Fig. 19. SEM 100µm image of FA100CCA90

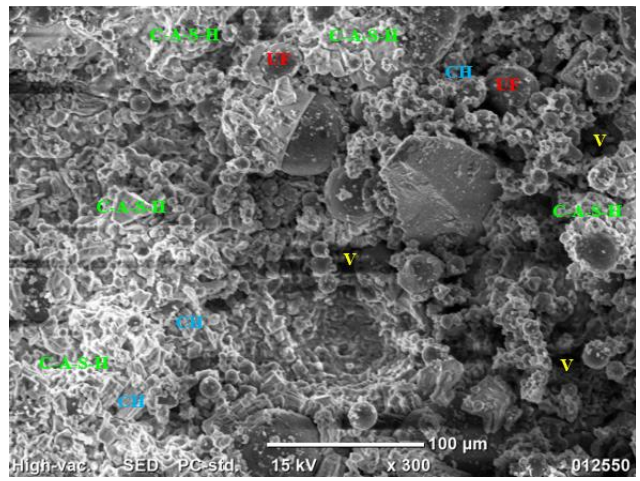


Fig. 20. SEM 100µm image of FA70CCA90

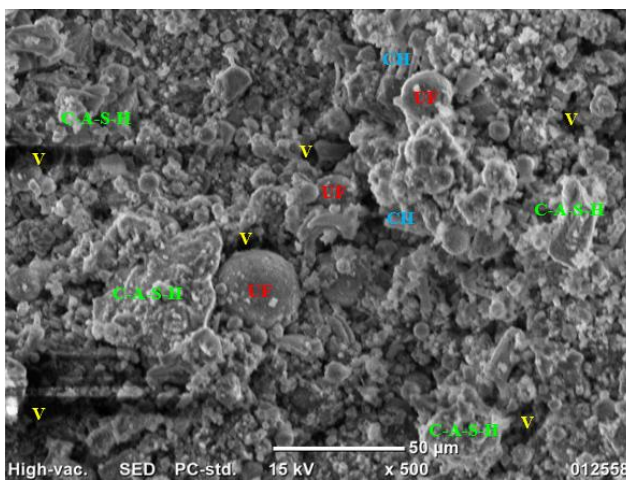


Fig. 21. SEM 50µm image of FA100CCA90

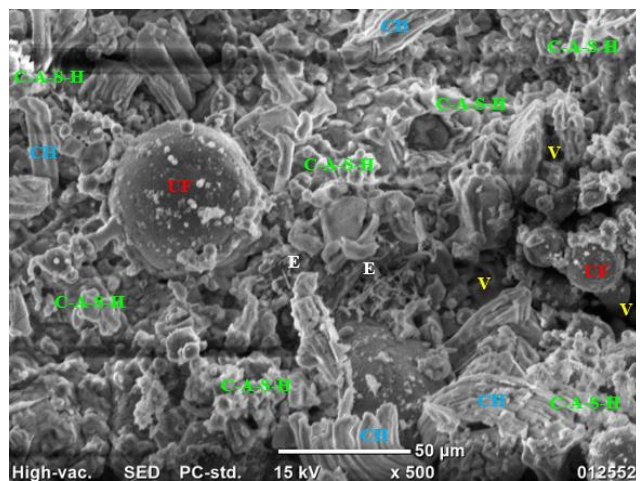


Fig. 22. SEM 50µm image of FA70CCA90

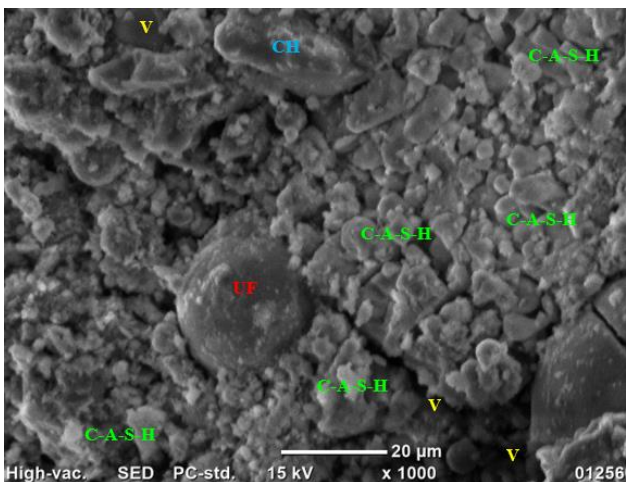


Fig. 23. SEM 20µm image of FA100CCA90

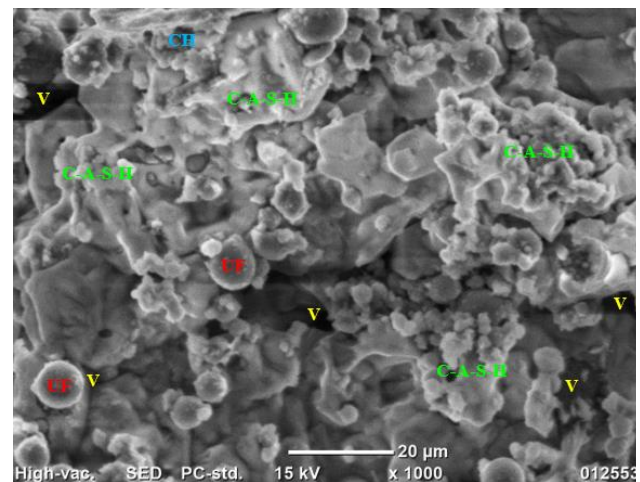


Fig. 24. SEM 20µm image of FA70CCA90

Here, C-A-S-H – represents C-A-S-H or N-A-S-H; v – voids; UF – Unreacted Fly ash; CH - Calcium Hydroxide. As it is seen from figure 12 to 21, as compared to fly ash binder mix less unhydrated products were found in fly ash-GGBS mix. Voids are visible in both the mixes. While SEM images suggest gel formation, precise identification of C-A-S-H and N-A-S-H requires techniques such as XRD, FTIR, or TGA. The current EDS analysis provides approximate elemental composition, which indicates the likelihood of these phases but does not confirm them definitively. The Energy Dispersive X-ray Spectroscopy (EDX) spectra presented in Figures 22 & 23 FA70 GGBS30 and FA100 provide insights into the elemental composition of pervious geopolymer concrete (PGC). The key elements detected

include oxygen (O), silicon (Si), aluminum (Al), calcium (Ca), sodium (Na), and iron (Fe), which are characteristic of geo polymerization reactions and the raw materials used in the concrete mix.

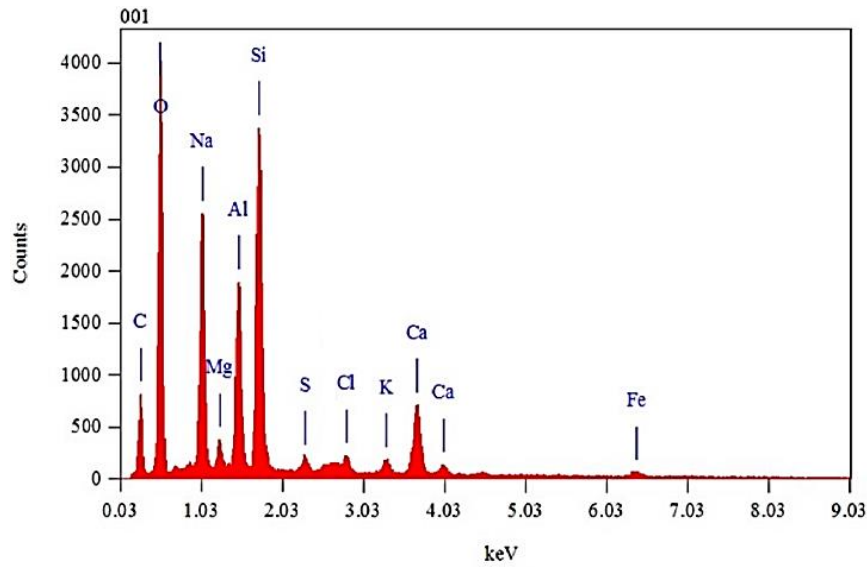


Fig. 25. EDS for mix FA100CCA90

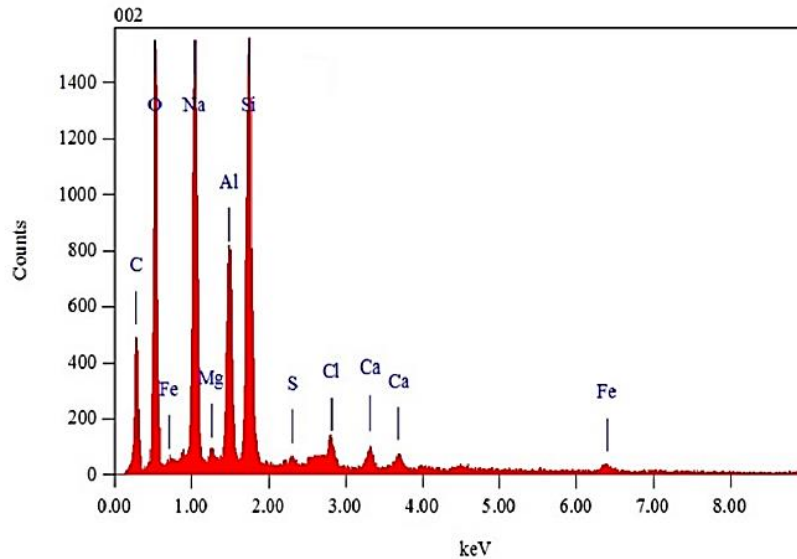


Fig. 26. EDS for mix FA70CCA90

The presence of high peaks of Si and Al confirms the primary components of the geopolymer matrix, which originate from fly ash (FA) and ground granulated blast furnace slag (GGBS). The polymerization of aluminosilicate precursors in an alkaline environment leads to the formation of sodium-aluminosilicate (N-A-S-H) and calcium-aluminosilicate (C-A-S-H) gels, which contribute to the strength and durability of the geopolymer concrete (28). The FA70 GGBS30 mix exhibits a higher Ca peak compared to the FA100 mix, suggesting the influence of GGBS in promoting the formation of C-A-S-H gel, which enhances mechanical properties (29). In contrast, the FA100 mix, which contains only fly ash, relies primarily on N-A-S-H gel, which may result in lower early-age strength but improved long-term durability (30). Oxygen is associated with silicate and alumina compounds, whereas sodium indicates the presence of an alkaline activator (NaOH or  $\text{Na}_2\text{SiO}_3$ ), essential for geo polymerization (31). The FA70 GGBS30 spectrum shows higher Ca and Fe peaks, indicating increased reactivity due to the presence of GGBS, leading to a denser matrix and improved mechanical properties (37). The FA100 mix exhibits a relatively higher Si/Al ratio, which suggests a more typical N-A-S-H gel structure, known for high durability and chemical resistance, making it suitable for pervious applications where water infiltration and sulfate resistance are crucial (35).

The EDX analysis suggests the geo polymerization of pervious concrete mixtures, with FA70 GGBS30 exhibiting higher calcium content for improved strength and FA100 showing a higher Si/Al ratio for enhanced durability. These findings align with previous research highlighting the benefits of using fly ash and GGBS in geopolymer concrete for sustainable and high-performance pervious pavement applications.

#### 4. Conclusions

- The strength of pervious geopolymer concrete increases with increase in the FCA and this increase was found to be 17.33 MPa for mix containing 70% CCA and 30% FCA.
- A mix containing 80% CCA and 20% FCA shows optimum percentage porosity which is equal to 22% and good infiltration rate with reasonable compressive strength that is without much loss in compressive strength.
- Mixes in which fly ash was partially replaced by GGBS (30% GGBS and 70% fly ash) shows significant increase in compressive strength without effecting porosity and infiltration i.e. a maximum compressive strength 15.33 MPa was achieved with 22% Porosity and 50.9 mm/min.
- The target infiltration rate of 50mm/min for slab specimen was achieved from Mix 1 to Mix 4 which was 62.3 to 50.9 mm/min, whereas for Mix 5 to Mix 8 the infiltration rate ranged from 33.53 to 25.46 mm/min. This is due to the increase in the finer aggregate content making the concrete denser.
- The porosity of all the mixes was within the range that is from 15% to 35% with maximum porosity observed in Mix 1 as there is no finer aggregate concentration.
- SEM images showed gel formations of suggesting C-A-S-H and N-A-S-H in 70% fly ash and 30% GGBS mixes resulted in the better strength of the mix under compression.
- The mixes containing 70% FA and 30% GGBS exhibited enhanced strength, possibly due to additional hydration products. However, the formation of ettringite cannot be confirmed without advanced characterization.

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