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Original Article

Investigation on the Effect of Concentration of NaOH with Partial Replacement of Fine Aggregate in Polyurethane-Foamed Geopolymer Concrete

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Abstract - *This study explores the effects of Polyurethane Foam (PUF) as fine aggregate and different NaOH molarity (M) to analyze the rheological behavior, hardened properties and microstructural behavior of Geopolymer concrete (GPC) and to optimize the fine aggregate replacement and NaOH molarity. For this purpose, In the PUF-GPC mix, the NaOH molarity of GPC varied from 10 to 14 at intervals of 2 with 1.5 % superplasticizers (SP) to improve the workability of GPC. The optimum workability and strength were attained at 15% of PUF replacement and 12 molarity of NaOH from slump values, compressive, split tensile, and flexural strength results. The results indicate that the optimal NaOH molarity of 12 M, with 15% PUF replacement, achieves the highest compressive strength (40.4 MPa), split tensile strength (5.15 MPa), and flexural strength (5.98 MPa) at 28 days. These findings highlight the potential of PUF-based GPC with optimized NaOH molarity as a sustainable alternative in construction applications. This study concluded that 15% PUF replacement and 12 M NaOH concentration with binder contents (fly ash-50% and GGBS-50%) and SP (2%) based GPC provided better workability, strength and microstructural behaviour*.

Keywords - *Polyurethane foamed geopolymer concrete, NaOH molarity, Fresh and hardened properties, Microstructural studies.*

1. Introduction

Globally, building construction is essential to life and life without it would be unimaginable [1], [2]. The number of people living on our planet will increase to over 10 billion [3]. Therefore, the construction industry must provide quality infrastructure to satisfy all human needs [4]. The consumption of construction materials is also rising, creating a need for alternative materials. At the same time, construction promotes economic growth by generating employment worldwide [5]. However, it influences natural resources in the environment [6]. Concrete is the most used material for building both houses and infrastructure. Its versatility, strength, and durability make it the basis for construction projects, from simple houses to big infrastructure projects such as bridges and dams [7], [8]. About 4500 MT of concrete is consumed globally each year [9]. Cement is important for making concrete. However, its production releases much CO_2, contributing to global warming [10]–[12]. In two decades, by 2050, the global demand for cement is projected to reach 6,000 million tons [9], [13]. In addition, the CO_2 emissions of this sector account for 5 to 7% of global manmade CO_2 contributions [14]. Cement is a material that is needed more on Earth than water [15]. It is the third-largest source of air pollution, like SOx, NOx, CO, dust, and harmful gases that cause greenhouse emissions [16]. These pollutants can cause smog, acid rain, breathing problems, and other harmful environmental effects [17]. Therefore, cement-free alternatives to concrete are needed to lower global CO_2 emissions [18]. The building sector is responsible for one fourth of CO_2 emissions [19].

Joseph Davidovits developed Geopolymer Concrete (GPC), which uses byproducts to create cement-free alternatives for making concrete [20], [21]. GPC is made from industrial by-products that are rich in alumina and silica, such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), metakaolin, rice husk ash, high calcium wood ash, nano silica, and waste glass powder. This type of concrete helps reduce CO_2 emissions during cement production and uses fewer natural resources [22]. GPC comprises Al, Si, sodium or potassium-based hydroxide, and silicate solutions [23], [24]. GPC combines Fly Ash (FA) and Ground Granulated Blast furnace Slag (GGBS). This mix gives the concrete good fresh properties and durability [25]. FA is an essential byproduct of coal combustion in power plants [26]. It is a rich amorphous aluminosilicate material that can mix with alkaline reagents and encounter geopolymerization, creating a strong and lasting binding structure similar to the function of cement in conventional concrete [27]. It consists of round, glassy particles with pozzolanic properties. About 0.6 to 0.7 billion tons of FA are produced annually. [28]. India made 0.2 to 0.25 billion tons from 202 coal-firing industries [29]. The vast amount of FA can support the global construction industry. It mainly contains reactive SiO_2 and Al_2O_3 [30]. FA improves workability and flowability [31]. FA-based GPC is a sustainable option with high compressive strength and durability [32]. GGBS is a supplementary material rich in amorphous silicate and aluminate [33], [34]. It aids the geopolymerization process [35]. GGBS has the properties to form additional cement-like compounds in GPC [36]. It improves GPC performance by enhancing workability, lowering the heat of hydration, and boosting long-term strength [37]. It is recognized as an eco-friendly binder and a viable alternative to traditional concrete in the construction industry [11].

On the other hand, fine aggregate, such as sand, is a crucial component in concrete, constituting about 70% of its volume and playing an essential role in filling the pores of concrete to withstand significant compressive forces. However, the growth of nations has dramatically increased construction activities, leading to massive consumption of natural resources like sand. Consequently, it has resulted in a shortage of fine aggregate and a rise in construction costs. Polyurethane foam (PUF) has low density and thermal conductivity, as well as mechanical and structurally comfortable material properties. Therefore, PUF is an effective alternative building material to traditional fine aggregates like sand in concrete, which offers several advantages that address the issues of resource scarcity, cost, and environmental impact. PUF is significantly lighter than traditional fine aggregates, which leads to lighter concrete structures. Furthermore, it has excellent thermal insulation properties, and its use as a fine aggregate can enhance the thermal efficiency of concrete structures.

In addition, construction costs may reduce the transportation of lighter foam materials. It can improve the durability of concrete by enhancing its resistance to chemicals and temperature fluctuations, which leads to longer-lasting structures with reduced maintenance needs. Therefore, PUF-based aggregate can serve as a substitute for traditional aggregate. However, there are several gaps in research concerning alternative fine aggregates of GPC. In recent studies, industrial byproducts such as FA and GGBS have been integrated into GPC formulations. However, due to its low density and excellent thermal properties, PUF makes an excellent GPC material, especially for weight reduction and energy efficiency applications. GPC with an increasing percentage of PUF should be optimized concerning rheological and mechanical properties. The impact of using PUF as a fine aggregate in GPC was not thoroughly studied in the literature despite some studies on GPC's general properties. For GPC to be successful in construction, its flowability, workability, and strength characteristics must be understood concerning the interaction between PUF and the binder matrix. Further, despite the extensive study of the geopolymerization process, more investigation of the hydration mechanism is needed, especially for alternative fine aggregates such as PUF. It can provide valuable insights into improving GPC's performance and durability by understanding how PUF affects these hydration products. The influence of NaOH molarity on GPC mixes containing alternative aggregates like PUF has not been extensively studied. The influence of sodium hydroxide molarities on the hardening and longevity of PUF concrete has not been systematically explored. NaOH concentration is a critical factor in geopolymerization, and its interaction with PUF can significantly alter the resulting mechanical and structural properties. Therefore, an investigation into the optimization of NaOH molarity for PUF-based GPC is needed.

This study explores polyurethane foam effects as fine aggregate with the following objectives: to analyse the rheological behaviour, and mechanical properties of different proportions of PUF as fine aggregate in GPC and to investigate the early, cured properties and microscopic structural changes of different NaOH molarities of optimised PUF in GPC. Also, this study provides recommendations for the future scope.

2. Materials and Methods

2.1. FA and GGBS

FA is used for GPC processing and activation and was acquired from the Tuticorin thermal power station in Tamil Nadu, India. The relative density of FA is 2.1, which appears to be a grey-coloured fine powder. GGBS was collected from the steel plant in Madurai, Tamilnadu, India, which is white and has a relative density of 2.9. The chemical compositions analyzed by XRF Bruker S8 Tiger, as mentioned in Table 1, indicated that FA consists of silica with 66.02%, alumina with 30.54%, and 1.41% calcium, whereas 3.03% other constituents are present. GGBS comprises 38.94% silica, 35.38% calcium, 17.23% alumina, and 8.45% other minor elements. The data reveal that FA and GGBS meet ASTM C618 and IS:12089-1987 standards, suitable for GPC based on aluminosilicate properties [38], [39].

Table 1. Chemical compositions of precursors

Compositions	FA	GGBS
Silica (%)	66.02	38.94
Alumina (%)	30.54	17.23
Calcium (%)	1.41	35.38
Minor elements (%)	3.03	8.45

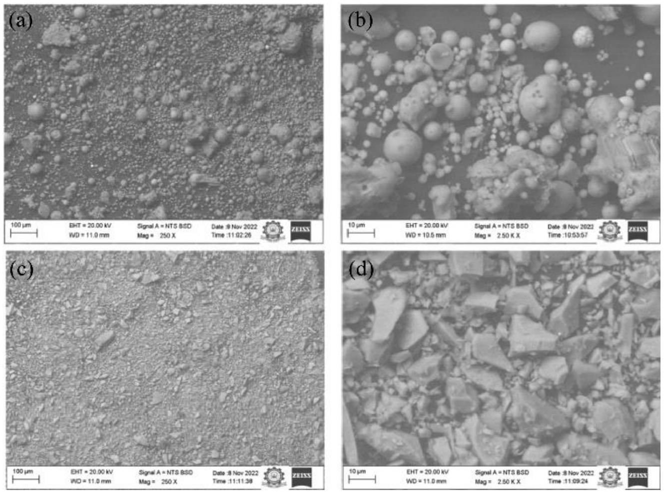

Fig. 1 SEM of FA (A&B) and GGBS (C&D)

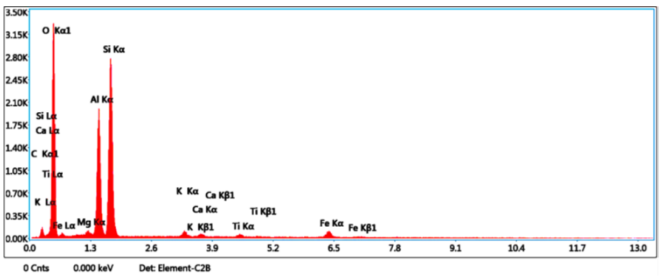

Fig. 2 Elemental composition of FA from EDAX

A scanning electron microscope (ZEISS-EVO 18 from Japan equipped with EDX was applied to analyze the morphology of FA and GGBS. The SEM images, as shown in Figure 1 (A&B), indicate spherical and smooth FA particles and composition is reported in Figure 2. The SEM images confirm the original structure of FA, which consists essentially of glassy, hollow, spherical particles called cenospheres [40]. The microstructure of FA agrees well with Davidovits' description. The important elements present in FA, such as Si, Al and Ca, are responsible for the binding properties of GPC.

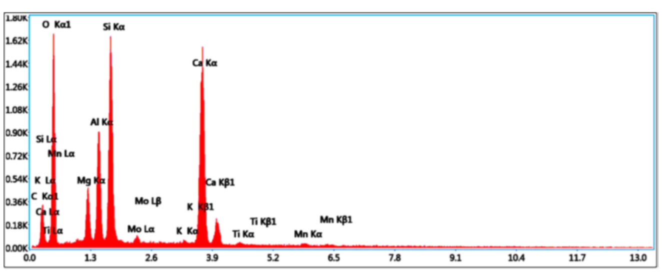

Fig. 3 Elemental composition of GGBS from EDAX

GGBS has irregular shapes and rough surfaces, as shown in Figure 1 (C&D), with its elemental composition in Figure 3. The SEM analysis of raw GGBS showed that its particles are sharp, angular, and irregular. The main components are Ca, Si, and Al, which act as pozzolanic materials, making it a viable substitute for cement in GPC.

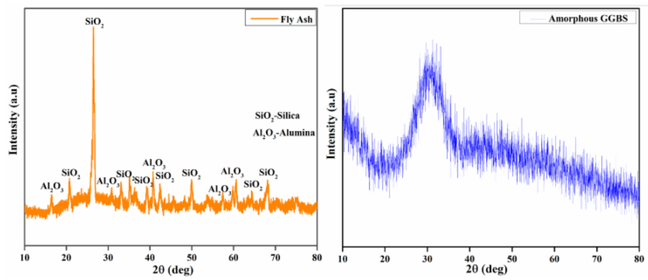

Fig. 4 XRD of FA and GGBS

Figure 4 shows XRD patterns for FA and GGBS. As shown in Figure 4, FA includes fine particle and crystalline constituents, which include silica and alumina. On the other hand, GGBS displays an amorphous appearance and multi-phases of materials.

2.2. Alkaline Activating Solution

In this study, NaOH and Na_2SiO_3 solutions were used as alkaline activators. Sodium hydroxide pellets with 98% purity were mixed with water, and Na_2SiO_3 solution was added to the prepared NaOH solution after 24 hours. The polymerization process begins when the Na_2SiO_3 solution is mixed, releasing heat, and requires one hour to cool before being added to the dry mixture. The ratio of Na_2SiO_3 to NaOH was maintained at 2.5, with NaOH molarity varied from 10 to 14 M in the present study.

2.3. Aggregates

M-Sand was collected from a nearby quarry with a relative density of 2.73, an average particle size of 2.65, and graded as zone II according to IS:383-1970 [41]. Coarse aggregates with a specific gravity of 2.83 were collected from the same place.

2.4. Super Plasticizers

Fresh concrete was made workable enough using a commercially available SP from Astra Chemicals, which contains polycarboxylic ether polymer, offering improved performance, durability, workability, strength, and water-reducing properties. Table 2 shows the characters of SP.

Table 2. Characters of SP

Properties	Superplasticizer
Product name	Polycarboxylic ether
Specific gravity	1.08 at 25^0C
pH	≥ 6.6
Chloride ions	< 0.24 %

3. Methods

3.1. Mix Design

In this experimental work, three different mixtures of GPC were prepared with binder contents such as FA and

GGBS at a mixture dosage of 370 kg/m^3. The NaOH concentrations were kept at 10 M to 14 M. The alkali solution ratio to the binder was at a constant value of 0.47, and the Na_2SiO_3 to NaOH of 2.5 was considered a constant value. 1.2% SP with binder weight added to geopolymer mix. The GPC mix specimen details are tabulated in Table 3.

Table. 3 The mix ratio of FA and GPC based on GGBS

Mix ID	FA kg/m^3	GGBS kg/m^3	Fine aggregate kg/m^3		Coarse aggregate kg/m^3	NaOH kg/m^3	M	Na_2SiO_3 kg/m^3	SP %
			M-Sand	PUF					
M10PUF0	185	185	781.481	0	1248.15	57.86	10	124.34	1.2
M10PUF5	185	185	742.411	39.07	1248.15	57.86	10	124.34	1.2
M10PUF10	185	185	703.33	78.15	1248.15	57.86	10	124.34	1.2
M10PUF15	185	185	664.261	117.2	1248.15	57.86	10	124.34	1.2
M10PUF20	185	185	625.181	156.3	1248.15	57.86	10	124.34	1.2
M12PUF0	185	185	781.481	0	1248.15	57.86	12	124.34	1.2
M12PUF10	185	185	742.411	39.07	1248.15	57.86	12	124.34	1.2
M12PUF15	185	185	703.33	78.15	1248.15	57.86	12	124.34	1.2
M12PUF20	185	185	664.261	117.2	1248.15	57.86	12	124.34	1.2
M14PUF0	185	185	625.181	156.3	1248.15	57.86	12	124.34	1.2
M14PUF0	185	185	781.481	0	1248.15	57.86	14	124.33	1.2
M14PUF5	185	185	742.411	39.07	1248.15	57.86	14	124.34	1.2
M14PUF10	185	185	703.33	78.15	1248.15	57.86	14	124.34	1.2
M14PUF15	185	185	664.261	117.2	1248.15	57.86	14	124.34	1.2
M14PUF20	185	185	625.181	156.3	1248.15	57.86	14	124.34	1.2

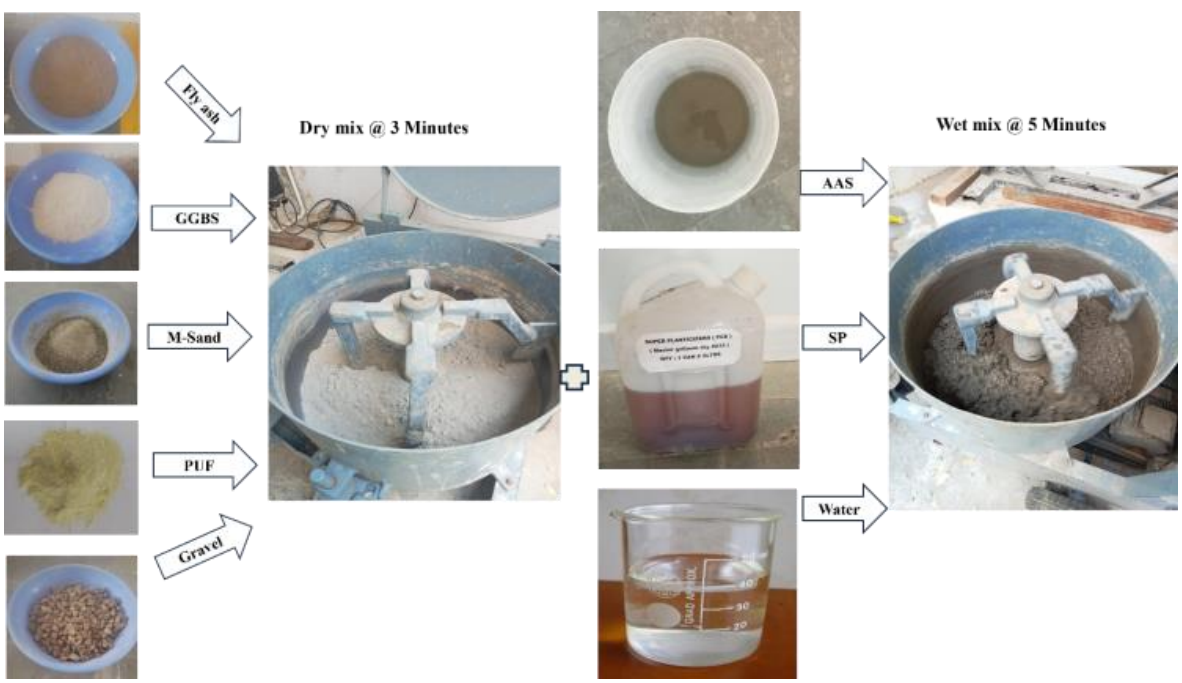

Fig. 5 The PUF- GPC preparation method

3.2. Specimen Preparation and Casting

FA, GGBS, partially replaced polyurethane foam as fine and coarse aggregates were dry mix blended for 2.5 minutes in a pan mixer (100-litre capacity). Subsequently, the alkaline solution, SP, was mixed for 3 minutes using wet mixing. Again, the fresh mix was mixed for a further two to three minutes to ensure the consistency of the mixture. GPC mix was undergone for slump flow test to evaluate the filing ability, passing ability and segregation to resistance. The mix was cast into cube, cylinder, and prism moulds. The specimens were left at ambient conditions for 24 hours after being poured into the moulds. After this initial curing period, it was stored for the 7th and 28th day for hardened properties testing. The PUF-GPC preparation method is shown in Figure 5.

4. Results and Discussion

4.1. Fresh GPC Properties

The flowability from different molarities of PUF-based GPC mixtures was measured, and the results are shown in Table 4. Figure 6 expresses the variations in slump values at different sodium hydroxide molarities. The slump values for PUF-GPC mixes varied between 7 and 12 cm.

The maximum yield value was measured at 12 M and the lowest at 10 M. The yield value decreased when the NaOH molarity increased from 10 M to 14 M. It was found that with the increase of NaOH concentration and PUF replacement at 15%, the settling value gradually decreased, which could be caused by the viscosity nature of the alkaline activator solution.

However, adding SP maintains the workability of PUF-based GPCs [42]. Therefore, M12PUF15 is an optimized mix proportion with 1.2 % SP% for better workability.

Table 4. Fresh properties of FA and GGBS-based GPC mixes

Mix ID	NaOH Molarity	Slump value in cm
M10PUF0	10 M	7
M10PUF5	10 M	8
M10PUF10	10 M	9
M10PUF15	10 M	10
M10PUF20	10 M	9
M12PUF0	12 M	9
M12PUF5	12 M	10
M12PUF10	12 M	11
M12PUF15	12 M	12
M12PUF20	12 M	10
M14PUF0	14 M	8
M14PUF5	14 M	9
M14PUF10	14 M	10
M14PUF15	14 M	11
M14PUF20	14 M	10

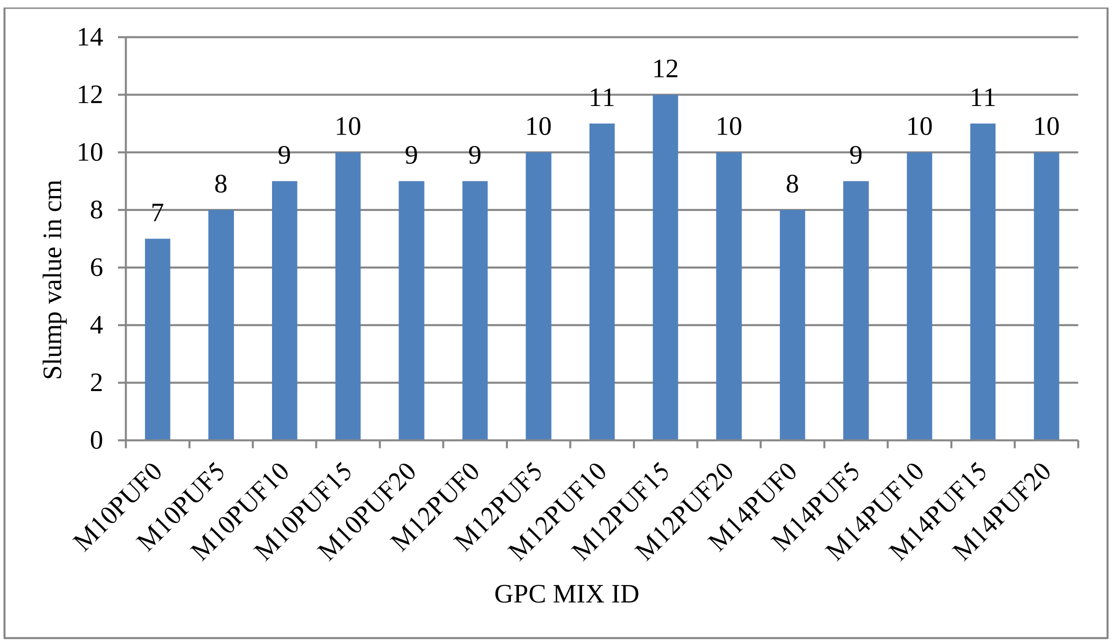

Fig. 6 Slump values of PUF-based GPCs

4.2. Hardened GPC properties

The hardened properties of the GPC are analyzed for performance and durability to optimize the replacement of PUF in different NaOH molarities. The compressive strength (CS) of GPC determines its suitability for different structural applications, such as in load-bearing elements. The split tensile strength (STS) and flexural strength (FS) properties of GPC are crucial for understanding the fine aggregate (PUF) replacement under bending and tension, which is essential for designing beams, slabs, and other structural components. In this way, the PUF replacement can be optimized, its suitability for NaOH molarity can be verified, and its sustainability credentials can be improved.

4.2.1. Compressive Strength of PUF-GPC

CS test results for various NaOH molarities are listed in Table 5, and Figure 7 depicts the influence of CS with PUF replacement (0 to 20 %) for fine aggregate and NaOH molarity of GPC at 7 and 28 days of curing periods.

It showed that increases in NaOH molarities with 15% replacement have shown positive effects on CS up to 12 M. The maximum CS (40.4 MPa) at 28 days is achieved when the NaOH molarity is from 12 M with 15% PUF replacement. Hence, the optimum molarity was attained with 12M and 15 % PUF replacement GPC (M12PUF15).

Table 5. Hardened properties of PUF-based GPC in different NaOH molarities

Mix ID	Molarity	CS (MPa)		STS (MPa)		FS (MPa)	
		7 days	28 days	7 days	28 days	7 days	28 days
M10PUF0	10 M	24.4	34.8	3.14	4.24	3.73	5.45
M10PUF5	10 M	24.9	35.6	3.56	4.75	3.98	5.88
M10PUF10	10 M	25.7	36.8	3.73	4.99	4.08	5.95
M10PUF15	10 M	24.6	35.2	3.36	4.35	3.73	5.45
M10PUF20	10 M	24	33.9	3.04	3.96	3.52	5.23
M12PUF0	12 M	28.3	38.7	3.27	4.48	4.13	5.64
M12PUF5	12 M	29.4	39.2	3.89	4.98	4.35	5.84
M12PUF10	12 M	28.8	39.6	3.38	5.04	4.82	5.92
M12PUF15	12 M	29.5	40.4	3.52	5.15	5.20	5.98
M12PUF20	12 M	28.1	38.2	3.31	4.77	4.22	5.75
M14PUF0	14 M	26.6	36.4	3.20	4.72	4.44	5.51
M14PUF5	14 M	28.5	38.8	3.56	4.94	4.67	5.65
M14PUF10	14 M	27.9	37.4	3.39	4.73	4.54	5.85
M14PUF15	14 M	26.3	35.9	3.14	4.58	4.46	5.54
M14PUF20	14 M	25.2	34.7	3.02	4.35	4.24	5.34

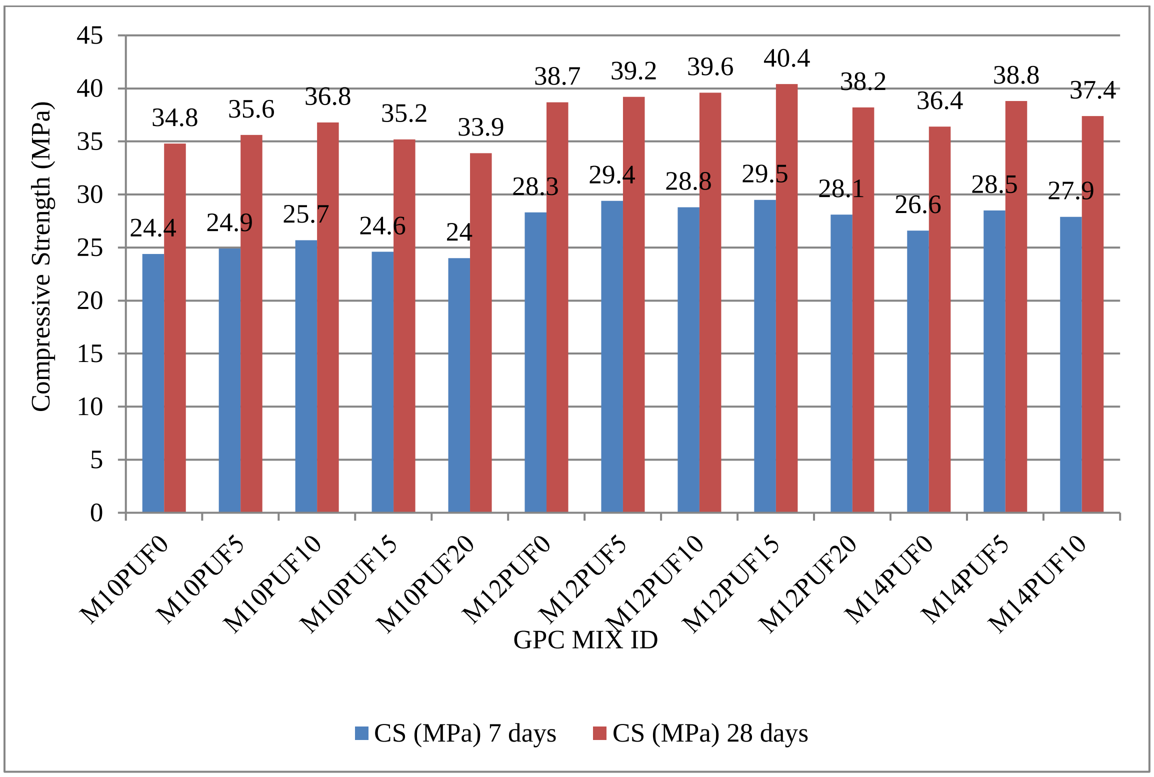

Fig. 7 CS (7 and 28 days) of PUF-based GPC with different NaOH molarities

4.2.2. Split Tensile Strength of PUF-GPC

The STS test results of GPC after 7 and 28 days are shown in Figure 8 and Table 5. The higher strength is attained when the molar of NaOH concentration increases from 10 M to 14 M. After 28 days, the combination of PUF (15%) based GPC at 12 M appeared highest STS of 5.15 MPa. The STS of 12 M with 15% of PUF was enhanced from 10 M and 14 M and other PUF replacements. Therefore, the optimum molarity is attained at 12 M with 15% PUF replacement for fine aggregate.

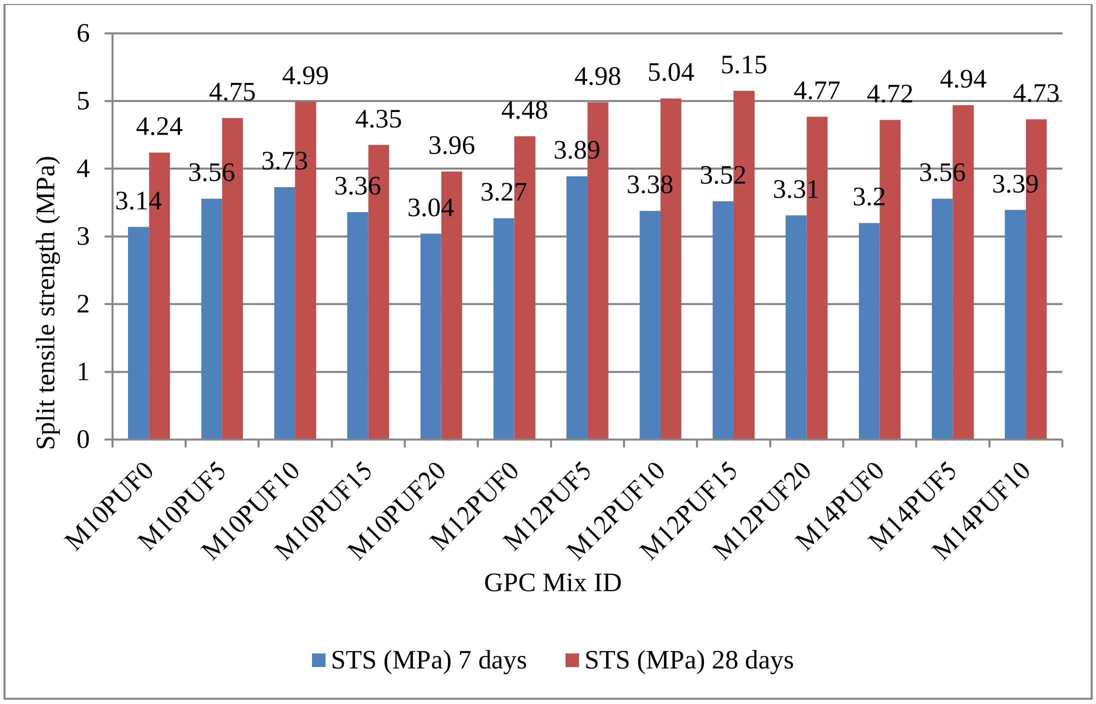

Fig. 8 STS (7 and 28 days) of PUF-based GPC with different NaOH molarities

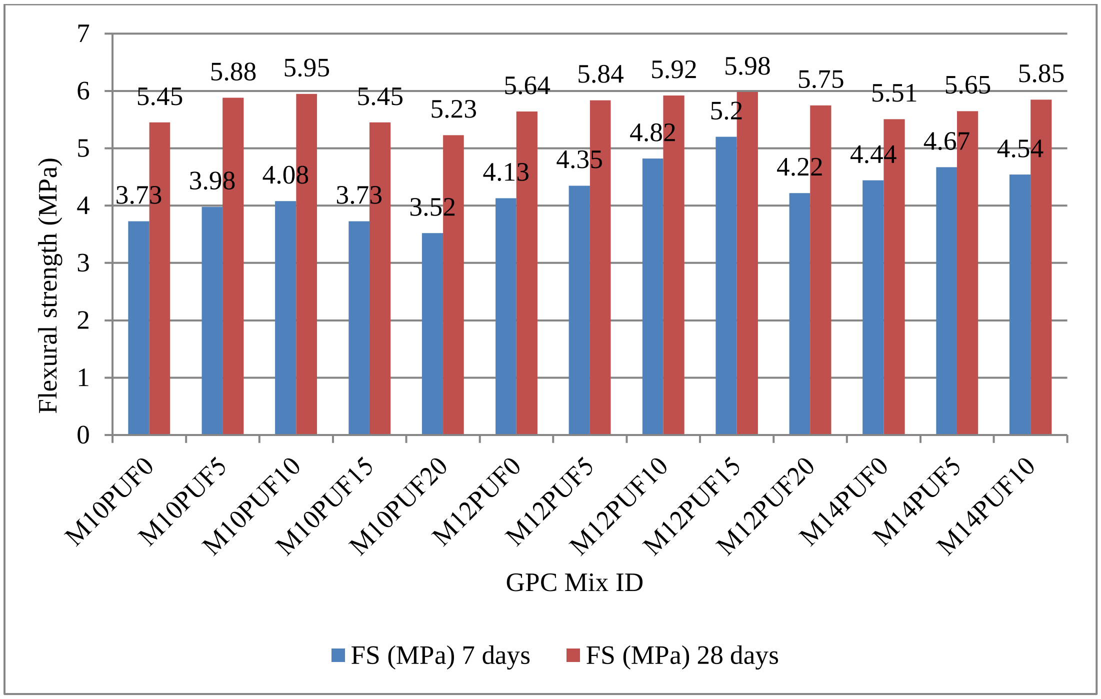

Fig. 9 FS (7 and 28 days) of PUF-based GPC with different NaOH molarities

4.2.3. Flexural Strength of PUF-GPC

FS test results for PUF-based GPC for 7 and 28 days after casting are shown in Figure 9 and Table 5. The PUF becomes stronger when the NaOH molar concentration increases from 10 M to 12 M. After 28 days, GPC with 12 M showed the highest FS of 5.98 MPa, the enhancement of FS compared to all other NaOH molarity. Hence, the optimum molarity was obtained as 12 M for PUF-GPC.

4.3. Microstructural Studies

4.3.1. XRD Analysis

XRD analysis was used to investigate the mineralogical properties of optimised PUF (15%) based GPC with different NaOH molarities (10 to 14 M) 28 days of curing at room temperature. The study of XRD analyses of different peaks (Figure 10) crystalline phases includes quartz, mullite and C-S-H (calcium silicate hydrate). The different NaOH molarities of GPC, observed with primary crystalline peak, consist of quartz (SiO_2) and mullite ($3Al_2O_3$-SiO_2). The primary strong peak positions of quartz (SiO_2) and mullite ($3Al_2O_3$-SiO_2), quartz peaks typically appear around 2θ-values of 24.61°, 26.29°, 27.32°, and 36.81° and mullite peaks occur around 2θ-values of 20.34°, and 42.90° [43]. Strong peaks in quartz and mullite indicate the coexistence of crystalline and amorphous phases in the geopolymer matrix. The amorphous phases, especially C-S–H, play an important role in binding the geopolymer particles together and contribute to the overall performance of the concrete [44].

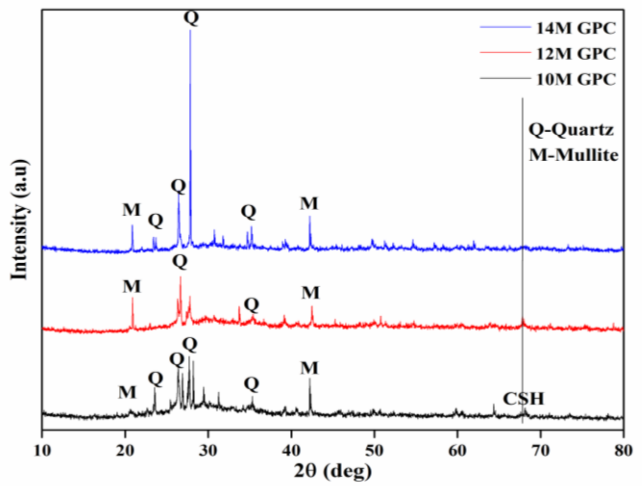

Fig. 10 XRD patterns of optimised 15% PUF-based GPC with 10 to 14 NaOH molarities

4.3.2. FITR Analysis

FTIR spectra of optimised PUF-GPC with different NaOH molarity to understand the chemical composition and bonding in the materials shown in Figure 11. The strong signals in the 3460 to 3780 cm-1 range are probably associated with H-O-H stretching vibrations [45]. This indicates the presence of water molecules or hydroxyl groups in the sample. O-H stretching vibrations involving O-H bonds generally occur at lower wavenumbers, typically 2130 to 2468 cm^{-1}.

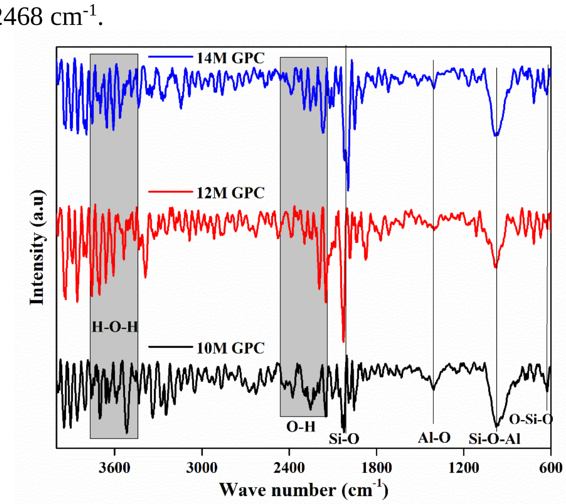

Fig. 11 FTIR spectra of optimised 15% PUF-based GPC with 10 to 14 NaOH molarities

The O-H stretching vibrations are related to water or hydroxyl groups [46]. A band at 2100 cm^{-1} in the FTIR spectra indicates the presence of Si-O groups in FA and GGBS source material [47]. The bands at 1367 cm^{-1} are due to the stretching and bending vibrations of the Al-O bonds exhibited by the aluminium presence from source materials [48]. The efflorescence phenomenon resulting from the geopolymerization process between Si and Al is associated with splitting absorption bands in the 900 cm-1 (Si-O-Al) ranges, respectively [49]. Overall, this result suggests that 12M of PUF- GPC functional groups and characterized bonding are possible, and this range may be related to the silica and alumina compounds that undergo polymerization during the geopolymerization process.

4.3.3. SEM with EDAX

Microstructural changes and elemental compositions of PUF-based GPC specimens were analyzed using SEM and EDAX techniques. Figures 12 (A- F) represent SEM images of optimised PUF (15%) GPC mixes with 10-14 M.

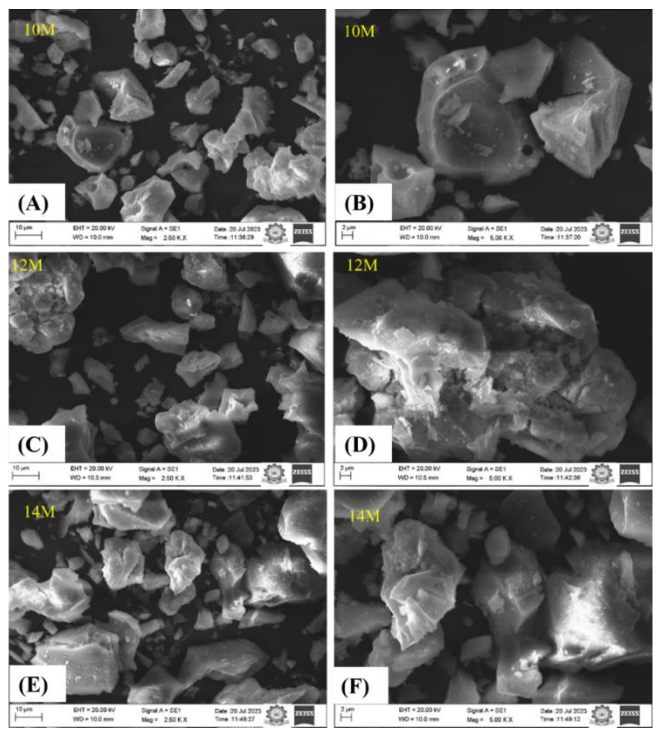

Fig. 12 SEM image of PUF (15%) - GPC of 10 M (A&B), 12 M (C&D) and 14 M (E&F)

The micrographs of GPCs appear compact and dense particles that claim the strength of PUF-based GPC at 12 M. The microstructure becomes denser with an increase in the molarity of NaOH. The 14 M specimen reveals a denser pozzolanic-binder matrix. Some voids and microspheres are seen, ascribed to air entrapment and the presence of FA, as seen in Figures 12 (A & B). Figures 12 (C & D) illustrate that the PUF-GPC specimen with higher molarity of NaOH contained fewer FA and GGBS particles, indicating an enhanced polymerization reaction and better compressive strength than the 10 M. The denser microstructure and increased strength in the 14 M GPC can be attributed to the greater extent of polymer gel formation, as shown in Figures 12 (E & F). The fine aggregates of PUF have more influence at the molarity of 12 M NaOH.

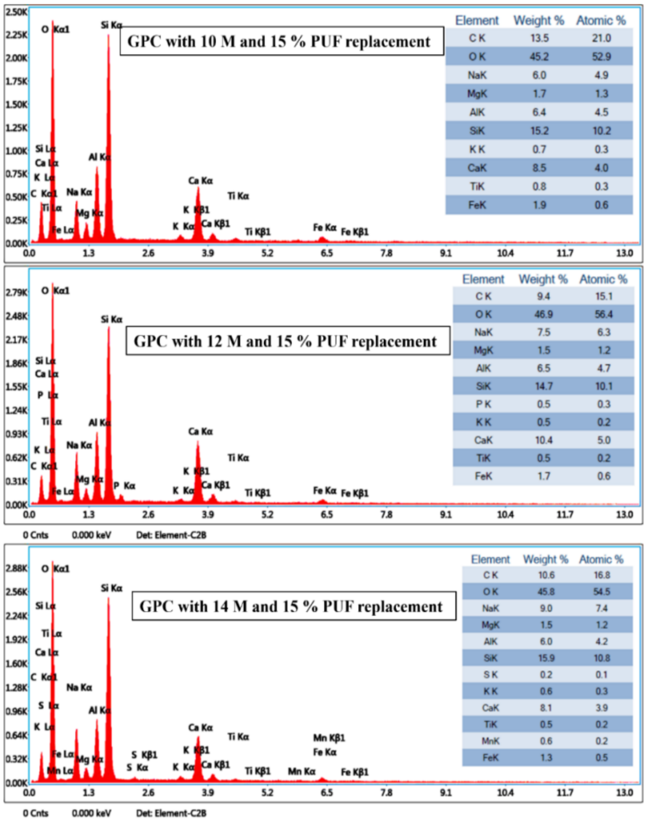

Fig. 13 EDX spectrum of PUF (15%) - GPC of 10 M (A&B), 12 M (C&D) and 14 M (E&F)

Si, Ca, Al, and Na are substantial elements and iron and calcium are also noted in EDAX spectra [50]. Figure 13 shows the EDAX spectra of 15% PUF-based GPC with different NaOH molarities from 10 to 14 M. Silica peak is from FA and GGBS existence and its reaction with the alkaline activator. Fe peaks were also observed in the PUF-GPC-based specimens, indicating the existence of FA [51]. 12 M GPC shows the higher elements Si, Ca, Na, Al, Fe, and Mg in Figure 13. Ca and Na weight percentages increase gradually from 10 M due to the GGBS and variation of NaOH molarity [52].

The EDX spectrum of 14 molarity PUF-based GPC shows the various elements Si, Ca, Na, Al, Fe and Mg. There are minor changes in the elemental distribution from 12 M, such as Na weight percentages and slight increment variations of NaOH molarity [52]. The elemental analysis conforms to the various molarity PUF-based GPCs compared with the major elements presented in each GPC from 10 to 14M.

5. Conclusion

This study concludes that the degree of polymerization is vital for the strength and quality of GPC. Maintaining good workability and strength is essential when incorporating PUF as an acceptable aggregate replacement; NaOH concentrations influence these properties. Optimizing the replacement percentage of PUF and NaOH molarity with FA and GGBS is crucial for achieving the best performance. The following conclusions were drawn:

- Workability is an important parameter that affects the strength of GPC. Optimum workability was achieved at 12 M NaOH with 15% PUF replacement for fine aggregate.
- Mechanical properties have an extensive impact on the durability and performance of concrete. The results indicated that GPC up to 15% PUF replacement possessed better mechanical properties. CS obtained was the highest at 12 M NaOH than other mixes with 10 M and 14 M NaOH concentrations. Further increases beyond 12 M resulted in decreased strength.
- Microstructure studies of optimized 15% PUF-based GPC in XRD, FTIR, and SEM-EDAX illustrated improved polymerization reactions up to 12 M NaOH. Further, XRD analysis confirmed that minerals such as quartz and mullite were present, contributing to the enhanced compressive strength. Incremental concentrations of NaOH molarity facilitated the formation of the C-S-H gel in the PUF-GPC.
- FTIR spectra of varied NaOH concentrations with 15% PUF replacement showed absorption bands related to H-O-H, O-H, Al-O, Si-O, and Si-O-Al bonds, which improved strength characteristics.
- SEM study showed that increased NaOH molarity increases the degree of polymerization and density of the particles, leading to increased strength. EDAX results showed important elements like Si, Ca, Al, Na, and Fe in the optimized PUF-GPC mixes.
- The durability of PUF-based GPC needs to be analyzed for future study, and specific structural applications of PUF-based GPC, such as prefabricated wall panels, sandwich panels and other building elements, must investigate the axial and vertical load bearing with this application.
- The lightweight properties of PUF-GPC make it ideal for reducing structural dead loads, enabling cost savings in foundations and transportation. PUF-GPC's thermal insulation capabilities can enhance energy efficiency, particularly in prefabricated elements like wall panels, sandwich panels, and lightweight slabs. To validate the material for critical applications, practitioners should prioritize durability testing, including resistance to chemical attacks and long-term weathering.

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