STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Investigation on Mechanical Properties of Geo Polymer Concrete With Fly Ash and Steel Fibers

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Abstract

The goal of this project was to manufacture fly ash-based geopolymer concrete (FAC), a more environmentally friendly substitute for conventional Portland cement concrete (OPC) by using fly ash (FA) in place of cement. The study discovered that the properties of FAC were comparable to those of OPC, and that the concrete's performance was greatly impacted by the geopolymer's polymeric nature. The geopolymerization process was started with an alkaline solution, and fly ash and alkaline mixes (NaOH and Na2SiO3) were made by combining the two solutions in a 1.2 ratio. The inclusion of hooked fibers to FAC resulted in enhanced post-cracking behavior, reduced shrinkage, and increased mechanical strength and ductility when compared to other types of fibers. In compliance with Indian norms, the study evaluated the flexural behavior, splitting tensile strength, and compressive strength of the FAC samples. The samples were tested for compressive, tensile, and flexural strengths using three different molarities: 8 M, 10 M, and 12 M. They also underwent a 28-day curing process in water. The results demonstrated that the FAC samples had significantly improved mechanical properties, with the maximum tensile and flexural strengths at 12 M molarity and higher compressive strength. The findings show that FAC is a viable and ecologically friendly replacement for OPC in a variety of construction applications due to its comparable mechanical performance to OPC.

Keywords: Aggregate, fly ash,geopolymer concrete, steel fiber, durability, NaOH, Na2SiO3, strengthimpact

INTRODUCTION

One of the most often used materials in the world is concrete, and one of its main ingredients is Portland cement. However, the environmental effects of Portland cement manufacture are substantial, especially when it comes to greenhouse gas (GHG) emissions and global warming[21]. Carbon dioxide (CO2) emissions from the manufacture of cement have increased dramatically in the last several decades. More specifically, a certain quantity of CO2 is released into the atmosphere for each ton of Portland cement produced. This leads to yearly GHG emissions of about 1.35 billion tons, or roughly 7% of all GHG emissions caused by humans. As a result, the manufacture of cement, an essential component of concrete, has a large environmental impact and raises greenhouse gas emissions globally.To address these environmental issues, scientists have created a substitute known as geopolymer concrete[1]. By using fly ash activated by an alkaline solution in place of Portland cement, this cutting-edge technique produces an environmentally friendly concrete alternative with characteristics comparable to regular Portland cement (OPC) concrete[2]. Although geopolymer concrete has not yet been widely incorporated into traditional waste processing procedures, it has the ability to recycle waste resources and lessen environmental effect[3].Fibers are frequently added to concrete to further increase its resistance to cracking brought on by wear and tear, overloading,

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Received Date: May 10, 2024
Accepted Date: August 27, 2024
Published Date: October 25, 2024

Citation: K.Hemantha Raja, K.Shyam Prakash. Investigation On Mechanical Properties Of Geo Polymer Concrete With Fly Ash And Steel Fibers. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S250–S260p.

or environmental factors[4]. These fibers reduce shrinkage, enhance mechanical strength and ductility under varied loads, and enhance the post-cracking behavior of concrete. The strength and stiffness of the link between the fibers and the cement matrix determines how effective the fibers are in concrete. A robust and inflexible fiber-cement matrix bond is essential in determining the mechanical properties of the composite. The fibers in the composite can make it more ductile after it splits, making it a stronger, more reinforced material overall[5].The mechanical qualities of concrete, such as its flexural and tensile strengths, stiffness, impact resistance, crack resistance, and toughness, can all be markedly improved by adding steel fibers. The alkali activators that are employed in the manufacture of geopolymers consist of varying proportions of NaOH and Na2SiO3[6]. The compressive strength of the geopolymer is increased as the amount of sodium hydroxide in the activating solution is increased. Sodium hydroxide requirements vary according to the kind of fly ash utilized in the geopolymer mixture. Furthermore, the geopolymer is strengthened by adding sodium silicate (Na2SiO3) to the alkaline solution (NaOH)[22]. The strength of the geopolymer is increased when sodium silicate is added because it increases the SiO2/Al2O3 and SiO2/Na2O ratios, which leads to additional Si-O-Si linkages.Numerous parameters, including fiber type, shape, length, cross-section, strength, binding properties, content, matrix strength, mix design, and mixing processes, affect how effective fibers are in concrete. Concrete's mechanical performance is enhanced by fibers in the following areas: toughness, ductility, fatigue resistance, durability, tensile and shear strength, and shrinkage. Particularly, crimped or straight steel fibers are inferior to hooked steel fibers in terms of flexural strength and energy absorption capacity[7]. Toughness is not considerably affected by the length of hooked steel fibers, according to research by Balaguru et al. (1992).Numerous investigations have examined diverse facets of geopolymer concrete. The impact of recycled concrete aggregate on the strengths of geopolymer concrete was examined by Anuar et al[20]. In order to comprehend the effects of temperature and activator concentration, Alonso and Palomo investigated the usage of metakaolin as a fly ash alternative. Sumajouw et al. concentrated on using fly ash-based geopolymer concrete to create thin, reinforced columns[19]. Pernica et al. investigated the impact of test conditions on the bending strength of geopolymer reinforced composites, whereas Bakharev examined the resilience of geopolymer to acid attack. Glass and steel fibers' impacts on geopolymer concrete's various strengths were studied by Vijai et al., while glass fiber-reinforced geopolymer concrete's properties were examined by Sathish Kumar et al. The impact of synthesizing variables on the workability and compressive strength of geopolymer mortar based on fly ash was studied by Bhowmick and Ghosh[9,10,11]. The impact of steel fibers on the mechanical and elastic characteristics of high-strength silica fume concrete was examined by Ghugal and Bhalchandra[18].When used as composite binders in concrete, geopolymers outperform conventional Portland cement in terms of compressive strength, durability, and carbon footprint. Their robust Si-O-Al network, which is created by a process akin to polymerization, gives them improved strength, thermal stability, and resistance to chemical assaults, which accounts for their polymeric characteristic[13].

The addition of steel fibers to geopolymer concrete enhances its elasticity, making it more resilient and adaptable[12]. Although geopolymer concrete is naturally more brittle than traditional concrete, the inclusion of steel fibers compensates for this by improving its toughness[17]. The presence of steel fibers helps to increase the concrete's flexural strength, compressive strength, and tensile strength, thus enhancing its overall mechanical properties.

Fly ash in geopolymer concrete significantly improves its mechanical properties when combined with an alkaline solution of increasing molarity[14]. The use of fly ash with a 12-molar alkaline solution leads to substantial enhancements in the concrete’s bonding and strength[16]. This combination results in increased flexural strength, compressive strength, and tensile strength, showing that fly ash-based geopolymer concrete can perform well mechanically, particularly when optimized with the right molarity and additives like steel fibers.

While the conclusions specifically mention fly ash-based geopolymer concrete, they do not directly address GGBS (Ground Granulated Blast Furnace Slag)[15]. However, the provided data indicates that

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

fly ash-based geopolymer concrete with a 12-molar alkaline solution and the inclusion of 0.5% steel fibers shows significant increases in flexural strength (32.83%), compressive strength (34.9%), and tensile strength (31.85%). If GGBS were included in the mix, it would likely contribute to further strength enhancements due to the known complementary effects of fly ash and GGBS in geopolymer mixtures, leading to even greater durability and mechanical performance.

MATERIALS AND METHOD

Materials

In this study, the basis material for the geopolymer was coal fly ash from VTPS Ibrahimpatnam, Andhra Pradesh, as illustrated in Fig. 1. Figure 2 shows hooked steel fibers measuring 30 mm in length and 0.5 mm in diameter that were purchased from Sarda Industrial Enterprises in Chennai. The alkaline activator used in this investigation was sodium silicate (Na2SiO3) plus NaOH in a 2:1 ratio that was purchased from RK Chemicals, Hyderabad, as Figures 3 and 4 illustrate. We purchased coarse aggregates with sizes of 20 mm and 12 mm from a nearby merchant, and fine aggregates that had been sieved to fit through a 4.5 mm sieve. The raw ingredients utilized in this are shown in Figs. 1, 2, 3, and 4.

Figure 1. Flyash.

Figure 2. Steel fiber

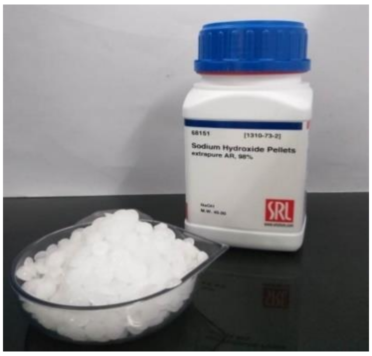

Figure 3. Na_2SiO_3.

Figure 4. NaOH.

Properties of Materials

The fly ash's properties, aggregates, and steel fibers are outlined below. Detailed analyses of these materials are provided in Tables 1, 2, 3and 4.

Table 1. Fly ash properties.

S.N.	Property	Values
1	Specific gravity	2.07
2	Fineness (m^2/Kg)	290
3	Bulk density (kg/m^3)	1100-1200
4	Colour	Light grey

Table 2. Aggregate properties.

S.N.	Property	Values
1	Specific gravity of F. A	2.71
2	Specific gravity of C. A	2.73
3	Fineness modulus of F. A	3.17
4	Fineness modulus of C. A	7.94

Table 3. Steel fiber Properties.

S.N.	Property	Values
1	Fiber type	Hooked-end
2	Length	30mm
3	Diameter	0.5mm
4	Density(gr/cm^3)	7.85
5	Tensile Strength(N/mm^2)	1225
6	Aspect Ratio	60

Table 4. Chemical Properties of NaOH & Na_2SiO_3.

S.N.	Property	NaOH	Na_2SiO_3
1	Molecular weight (g/mol)	40	122.08
2	Density (g/mol)	2.13	1.39
3	H_2O	-	64.8
4	SiO_2	-	28.7
5	Na_2O	-	8.9
6	PH	13.5	-
7	Colour	white	white

LITERATURE REVIEW

The application of geopolymer concrete has gained momentum in recent years, driven by its potential for sustainability and performance enhancement over traditional concrete. Numerous studies have explored the mechanical properties and durability of fly ash-based geopolymer concrete, particularly with the incorporation of steel fibers, which are known to significantly improve tensile strength and impact resistance.

Charkhtab Moghaddam [1]. investigated the mechanical properties of fly ash-based geopolymer concrete modified with crumb rubber and steel fibers, revealing that the addition of these fibers enhances performance under both ambient and sulfuric acid exposure. This highlights the composite's robustness in aggressive environments.

Meor Ahmad Faris [2]. compared the effects of different types of steel fibers on the properties of Malaysian fly ash-based geopolymer concrete, emphasizing changes in slump, density, water absorption, and mechanical properties. His findings indicate that the type of steel fiber significantly influences the workability and strength of the geopolymer mix, suggesting that careful selection of fiber type can optimize performance.

The influence of steel fibers on the mechanical properties and impact resistance of lightweight geopolymer concrete was further examined by Islam and Alengaram [3]. Their research confirmed that steel fibers not only enhance strength but also improve the ductility and energy absorption capacity of the concrete, making it suitable for structural applications.

Vijai K [4]. demonstrated the effects of steel fiber inclusion on the properties of geopolymer concrete composites, noting improvements in flexural strength and post-cracking behavior. This study underscores the importance of fiber reinforcement in mitigating brittleness and enhancing durability.

Gomes [5]. provided insights into applied fracture mechanics, which are essential in understanding the crack propagation behavior in fiber-reinforced concrete. This theoretical background supports the findings on the improved fracture toughness of geopolymer composites.

In the realm of concrete sustainability, Mehta and Monteiro [6]. discussed the microstructure and material properties that can be manipulated to reduce environmental impacts. Their work aligns with Davidovits' [8]. exploration of high-alkali cements as an alternative for 21st-century concretes, reinforcing the necessity for innovative materials like geopolymers.

Research by Gunasekara et al [10]. focused on the long-term mechanical properties of different fly ash geopolymers, providing critical data on the durability and performance of these materials over time. The insights gained are pivotal for the practical application of geopolymer concrete in construction.

Hardjito et al [11]. detailed the development of fly ash-based geopolymer concrete, emphasizing mix design considerations that optimize the use of local materials. This foundational work laid the groundwork for further advancements in geopolymer technology.

Chindaprasirt et al. [12]. studied the workability and strength of high calcium fly ash geopolymer mixes, demonstrating that the chemical composition of the fly ash significantly affects the properties of the resulting concrete. Their findings are crucial for tailoring geopolymer formulations to specific requirements.

Rangan's [13][15]. work on mix design principles for fly ash-based geopolymer concrete has been influential, providing guidelines that have been adopted in various research contexts, including recent modifications to align with Indian standards [14].

Finally, studies on the effects of fiber reinforcement, such as those by Bhutta et al. [16]. Tadepalli et al [17]. and Bencardino et al. [18]. highlight the enhancements in flexural behavior and stress-strain characteristics of geopolymer composites when reinforced with steel and polypropylene fibers. These findings support the notion that fiber reinforcement is critical for improving the mechanical integrity of geopolymer concrete.

In conclusion, the literature demonstrates that the incorporation of steel fibers in fly ash-based geopolymer concrete substantially improves its mechanical properties and durability. Future research should continue to refine mix design and explore the synergies between different types of fibers and supplementary materials to further advance the field of geopolymer concrete.

EXPERIMENTAL WORK

Geopolymers have garnered significant attention in the construction industry due to their potential to enhance sustainability while offering comparable mechanical properties to traditional concrete. This study aims to explore the effectiveness of using sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) as alkaline activators in the production of geopolymer composites, specifically incorporating fly ash and steel fibers. The utilization of fly ash not only recycles industrial by-products but also contributes to the reduction of carbon emissions associated with traditional cement production.

The experimental work involved preparing NaOH solutions of varying molarities (8M, 10M, and 12M) to evaluate their influence on the reactivity of the geopolymer mix. Accurate measurements of NaOH and Na2SiO3 were made to ensure optimal performance of the alkaline activator. Following the mixing of raw materials—including fly ash, steel fibers, fine aggregates, and coarse aggregates—the alkaline solution was introduced to create a homogenous paste.

This paste was then cast into various molds (cubes, prisms, and cylinders) to facilitate testing of mechanical properties such as compressive, tensile, and flexural strengths. The curing process, which was conducted at ambient temperatures as well as under elevated conditions, aimed to simulate real-world scenarios for structural applications. A consistent water-to-cement ratio of 0.45 was maintained throughout the mix design to ensure reliability in the results.

A total of 27 samples were evaluated after a curing period of 28 days, providing a comprehensive analysis of the geopolymer's performance against conventional concrete. The findings of this study not only contribute to the growing body of knowledge on geopolymer technology but also highlight the viability of using alternative materials in concrete applications, paving the way for more sustainable construction practices.

Solution Preparation

One day before usage, NaOH solutions were made by dissolving NaOH pellets for three distinct molarities 8M, 10M, and 12M in one liter of distilled water in a volumetric flask, as shown in Figs. 5 and 6. During the preparation step, the molecular weight of NaOH for each molarity was used to determine how much was needed. A concentrated Na2SiO3 solution was also added in with precise weight ratios. To achieve appropriate reactivity, this alkaline activator a mixture of NaOH and Na2SiO3 was subsequently combined with the steel fibers and fly ash.

Mixing Process

Initially, the fly ash, steel fibers, fine aggregates, and coarse aggregates were combined in specific weight ratios and mixed for a few seconds. Subsequently, After adding the alkaline activator solution, the mixture was agitated to produce a homogenous paste. This mixing process continued for approximately 10 minutes for each batch. The total mass of all materials in the geopolymer paste was kept consistent. After making the paste, it was put into three different molds: cubes (150x150x150 mm), prisms (300x150 mm), and cylinders (100x100x500 mm). The specimens were cured in their molds at room temperature and between 40ºC to 80ºC for 24 hours. The specimens were evaluated for compressive, tensile, and flexural strengths after being taken out of the molds, and the outcomes were contrasted with those of regular concrete. The specimens were cured in water for 28 days after these experiments. A total of nine cubes, nine cylinders, and nine prisms made up the 27 samples that were cast.

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Figure 5. NaOH.

Figure 6. Na_2SiO_3.

Mix Design and Proportion

In this paper, we used The water cement ratio 0.45 was used throughout the mix.

Mix Design

Design Constraints

Materials Calculation for 1m^3

Quantity of concrete	= 1m^3
Flyash	= 414.00kg/m^3
Fine aggregate	= 660.00kg/m^3
Coarse aggregate	= 1136.00kg/m^3
NaoH	= 0.531 Lit
Na_2sio_3	= 1.062 Lit

Sample Mix Preparation

For testing compression strength of cubes, mould size of 150×150×150mm was used and for split tensile strength (cylinder) the size used is 300mm×150mm and for flexural test (prism) the size is used 100×100×500mm and also for concrete permeability test cubes were employed with the size of 150×150×150mm .

A total of 27 samples were examined following a 28-day curing period. Nine prisms, nine cylinders, and nine cubes were among them. The materials used to create the samples included fly ash, steel fibers, fine and coarse aggregates, and a mixture of NaOH and Na2SiO3, according to the precise weight ratios and molarities specified for the study.

RESULT AND DISCUSSION

Strength in Compression

Compaction strength testing was done in compliance with IS standard 516-1959. After 28 days, the results, which are displayed in Table 5, demonstrate a 32.83% increase in compressive strength. The presence of steel fibers combined with the solutions significantly influences this enhancement. The increase in Na ions within the system is crucial for geopolymerization, as these ions balance the charges and form alumino-silicate networks, acting as the binder in the mixture. This process contributes to improved mechanical properties and enhanced strength. Figure 7 illustrates the compression test, while Figure 10 provides a graphical representation of the compressive strength results.

Table 5. Compressive Strength.

Molarties	Sample 1	Sample 2	Sample 3
8M	43.5	42	45
10M	43	46	45
12M	45	47	47.5

Tensile Strength in Split

The tensile Strength in Split test was conducted in accordance with IS specification 516-1959. The results, presented in Table 6, demonstrate that the tensile Strength in Split increased by up to 34.9% after 28 days as the solution's concentration was elevated, which also enhanced the elasticity. Figure 8 illustrates the tensile Strength in Split.Figure 11. Clearly shows the tensile results, in graphicall view

Table 6. Tensile Strength in Split

Molarties	Sample 1	Sample 2	Sample 3
8M	2.9	3.5	3.4
10M	3.7	3.3	2.8
12M	3.8	3.6	3.3

The IS standard 516-1959 was followed in conducting the flexural strength test. Table 7 presents the results, indicating that the Flexural strength rose by up to 31.85% after 28 days, as the concentration of the alkaline solution and bonding improved. However, beyond this point, the strength started to decrease. The concrete's nominal flexural strength values at 28 days are also provided. Figure 9 displays the flexural strength, while Figure 12 offers a graphical representation of these results.

Figure 7. Compression test.

Figure 8. Split tensile test.

Table 7. Flexural strength.

Molarties	**Sample 1**	**Sample 2**	**Sample 3**
8M	7.11	7.3	6.8
10M	7.2	7.41	7.51
12M	7.7	7.58	6.98

Figure 9. Flexural test.

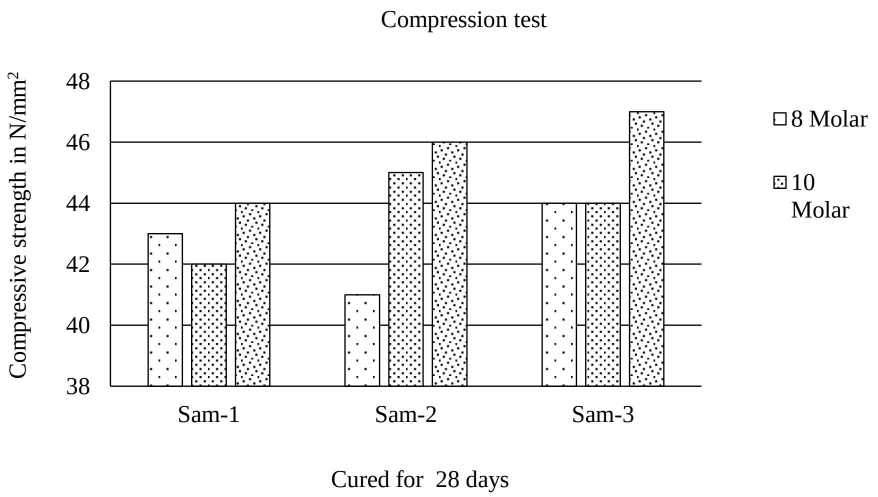

Figure 10. Compressive strength.

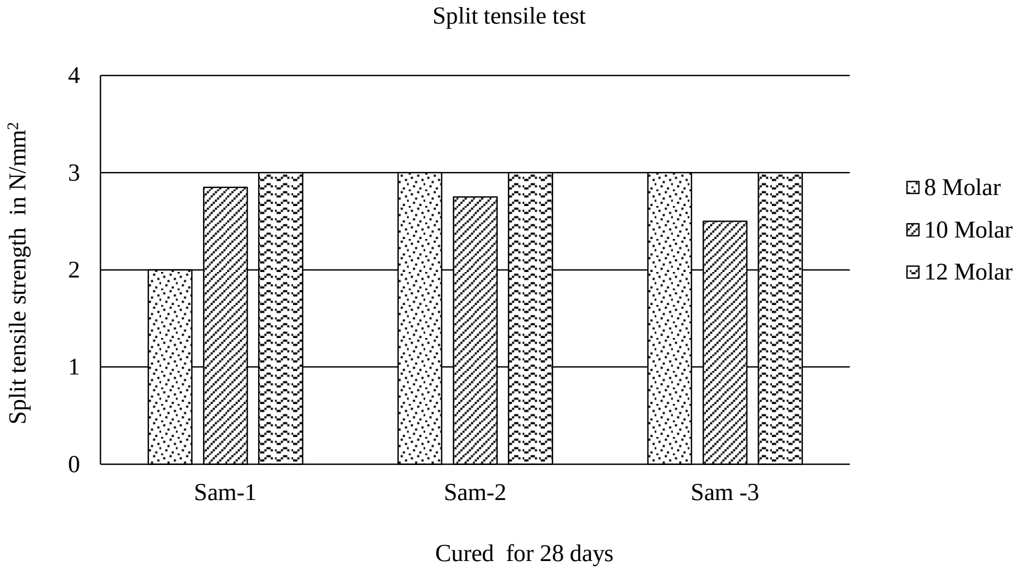

Figure 11. Split tensile strength.

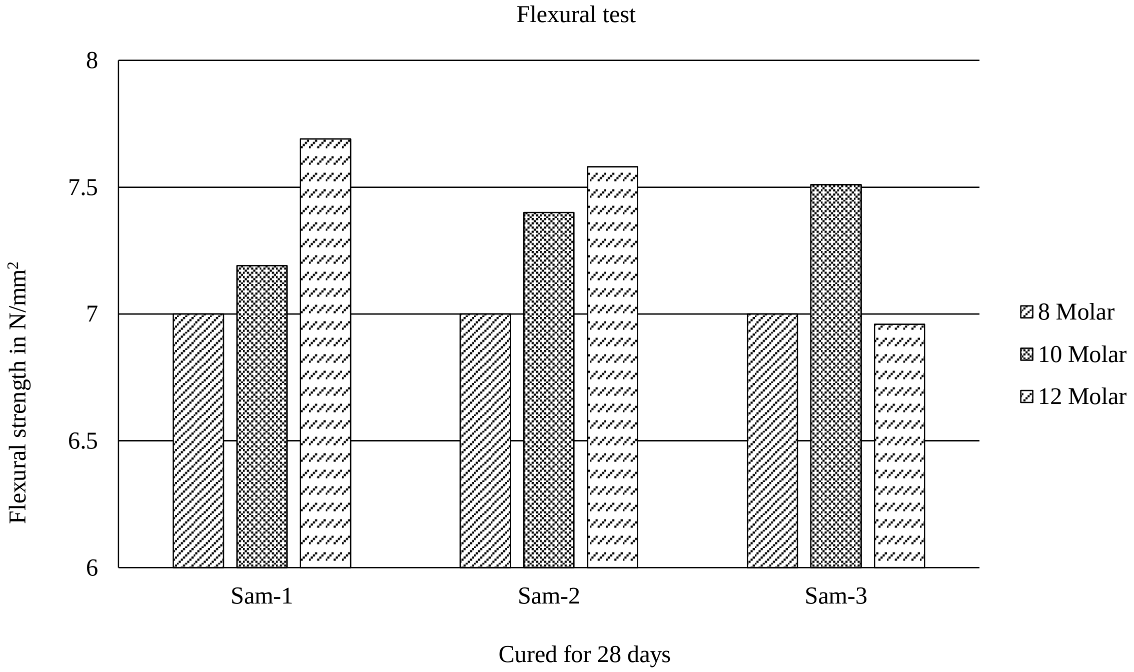

Figure 12. Flexural strength.

CONCLUSION

1. Geopolymer concrete represents a significant innovation in construction materials by completely replacing traditional cement with industrial byproducts. This substitution reduces cement usage and repurposes waste products like fly ash, helping to mitigate global warming. Steel fibers are added to geopolymer concrete, which increases its elasticity and makes it a more resilient and adaptable building material even though it is by nature more brittle than regular concrete.
2. Experimental results reveal that increasing the molarity of alkaline solutions enhances the bonding within the concrete. Fly ash-based geopolymer concrete, with a 12-molar alkaline solution and reinforced including 0.5% steel fibers, demonstrates substantial improvements in mechanical properties. Specifically, the flexural and compressive strengths, and tensile strength increase by up to 32.83%, 34.9%, and 31.85%, respectively.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

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