Global Research journal of Natural Science and Technology (GRJNST)
Volume: 03 - Issue 3 (2025)
p.ISSN: 2790-7643 e.ISSN: 2790-7651

Investigation of Mechanical properties of Concrete composed of Bagasse Ash and Lime subjected to Ammonium Nitrate Attack

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Abstract: *The study addresses the challenge of concrete deterioration at the Fatima Fertilizers Corporation Limited (FFCL) Sadiqabad facility, caused by exposure to ammonium nitrate. It explores the use of lime and bagasse ash as partial replacements for cement to improve concrete's resistance to this chemical. The research focuses on identifying the optimal replacement percentage for maximizing strength and durability, particularly for M15 grade concrete. Experimental results show that a 20% replacement ratio of lime and bagasse ash offers the highest resistance to ammonium nitrate, with only a 15.11% decrease in compressive strength, compared to a 33.04% reduction with no replacement. Similarly, the 20% replacement ratio achieves the lowest reduction in tensile strength at 15.91%, compared to a 40.21% loss with no replacement. Additionally, the 15% replacement ratio enhances* *strength during water curing, showing significant increases in compressive and flexural strength. Overall, both lime and bagasse ash are effective in improving concrete durability, with the 20% replacement offering the best performance under ammonium nitrate.*

Keywords *Concrete deterioration Ammonium Nitrate, Lime, Bagasse ash, Durability, Strength properties strength.*

Introduction

Concrete, as the backbone of modern infrastructure, plays an indispensable role in the construction industry due to its versatility, durability, and cost-effectiveness. However, despite its widespread usage, concrete faces significant durability challenges when exposed to aggressive environmental conditions. Among these, exposure to chemical substances such as ammonium nitrate commonly found in fertilizers presents a particularly severe threat. The resultant chemical attacks can lead to deterioration of the concrete's structural integrity, ultimately shortening the lifespan of the infrastructure (Mehta and Monteiro 2014). Addressing these issues has become critical, especially in industrial sectors where ammonium nitrate exposure is prevalent, as it directly impacts the safety and longevity of concrete structures (Neville 2011; Rajasekar et al. 2018).

In recent years, the focus has shifted towards enhancing the durability of concrete through the use of alternative materials that can partially replace traditional cement. This approach not only aims to improve the mechanical properties of concrete but also promotes sustainability by utilizing industrial byproducts (Khalil et al. 2021). Two such materials that have garnered significant attention are bagasse ash, a byproduct of the sugarcane industry, and lime, a byproduct of the fertilizer industry. Both materials are abundantly available in regions like Sadiqabad, Pakistan, and offer a promising solution to the ongoing problem of concrete degradation (Kumar and Ramesh 2018).

Concrete's primary advantage lies in its adaptability and strength, which make it suitable for a wide range of construction applications (Taylor 1997; Siddique 2008). Its global usage spans from residential buildings to large-scale infrastructure projects, making it one of the most consumed human-made materials. However, concrete is not without its limitations, particularly when exposed to chemical environments. Among the various chemicals that can cause concrete degradation, ammonium nitrate is especially problematic. Commonly used as a fertilizer, ammonium nitrate can initiate chemical reactions within the concrete matrix, leading to the formation of expansive products that cause cracking and spalling (Neville 2011). This issue is particularly relevant in agricultural and industrial regions where ammonium nitrate exposure is inevitable (Mehta and Monteiro 2014; Cordeiro et al. 2009).

Given the importance of maintaining the structural integrity of concrete, especially in critical infrastructures, researchers have explored various methods to enhance concrete's resistance to chemical attacks. One such approach involves the partial replacement of traditional cement with alternative materials that can improve the chemical resistance and durability of concrete (Rajasekar et al. 2018). Bagasse ash, derived from the combustion of sugarcane bagasse, is one such material. Rich in silica, bagasse ash exhibits pozzolanic properties, making it a viable alternative to cement. Similarly, lime, a byproduct of the fertilizer industry, offers several benefits when used in concrete, including improved workability, reduced water demand, and enhanced resistance to environmental elements (Khalil et al. 2021).

The utilization of these byproducts not only addresses the issue of concrete degradation but also contributes to environmental sustainability (Mehta and Monteiro 2014; Khalil et al. 2021). By repurposing waste materials from the sugarcane and fertilizer industries, the construction industry can reduce its reliance on traditional cement, which is known for its high carbon footprint (Neville 2011). This aligns with global efforts to promote sustainable construction practices and reduce the environmental impact of infrastructure development (Rajasekar et al. 2018).

Problem Statement

The problem of concrete degradation due to ammonium nitrate exposure is particularly pronounced in regions with significant agricultural and industrial activity. The Fatima Fertilizers Corporation Limited (FFCL) facility in Sadiqabad, Pakistan, serves as a case study for this issue. The facility, which is located in a region where ammonium nitrate is widely used, has reported accelerated deterioration of its concrete structures. This deterioration poses a significant threat to the safety and operational efficiency of the facility, highlighting the urgent need for a solution that can enhance the durability of concrete in such environments.

Traditional concrete, composed primarily of cement, fine and coarse aggregates, and water, lacks the necessary chemical resistance to withstand prolonged exposure to ammonium nitrate. The chemical reactions triggered by ammonium nitrate can lead to the formation of expansive products, which structural failure. This problem is exacerbated by the fact that concrete structures in industrial facilities exert internal pressure on the concrete matrix, causing cracking, spalling, and ultimately, are often subjected to continuous exposure to chemicals, making them particularly vulnerable to degradation.

Given the critical role of concrete in infrastructure, finding a solution to this problem is essential. The use of bagasse ash and lime as partial replacements for cement offers a potential solution, as these materials have been shown to improve the chemical resistance and mechanical properties of concrete. However, there is a need for further research to determine the optimal replacement ratios and to evaluate the long-term performance of concrete incorporating these materials under ammonium nitrate exposure.

Research Aim

The primary aim of this research is to evaluate the effectiveness of bagasse ash and lime in enhancing the durability and mechanical properties of concrete, particularly in environments where it is exposed to ammonium nitrate. The research seeks to determine the optimal replacement percentages of lime and bagasse ash to maximize concrete strength while maintaining workability. Additionally, the study aims to assess the resistance of M20 grade concrete, with partial cement replacement, to ammonium nitrate attack. The research also intends to explore the feasibility of using lime and bagasse ash as sustainable alternatives to cement in concrete production, thereby contributing to the development of more durable and environmentally friendly construction materials.

The specific objectives of this research are as follows:

- To determine the optimal replacement percentages of lime and bagasse ash for improving the strength and durability of concrete.
- To evaluate the impact of partial cement replacement on the resistance of M20 concrete to ammonium nitrate attack.
- To assess the long-term performance of concrete incorporating lime and bagasse ash in terms of compressive strength, split tensile strength, and flexural strength.
- To explore the potential environmental benefits of using lime and bagasse ash as sustainable alternatives to traditional cement in concrete production.

Materials and Methods

Background

The methodology in this study outlines the process of evaluating the impact of lime and bagasse ash as partial replacements for cement on the performance of concrete. The experiments were designed using the M15 mix, which is suitable for applications such as residential buildings, pavements, and low-rise structures. The focus of this research is to measure the effects on durability, compressive strength, split tensile strength, and flexural strength. All experimental procedures, from material procurement to testing, are detailed to ensure reproducibility and accuracy. Figure 1 shows the flow chart of methodology.

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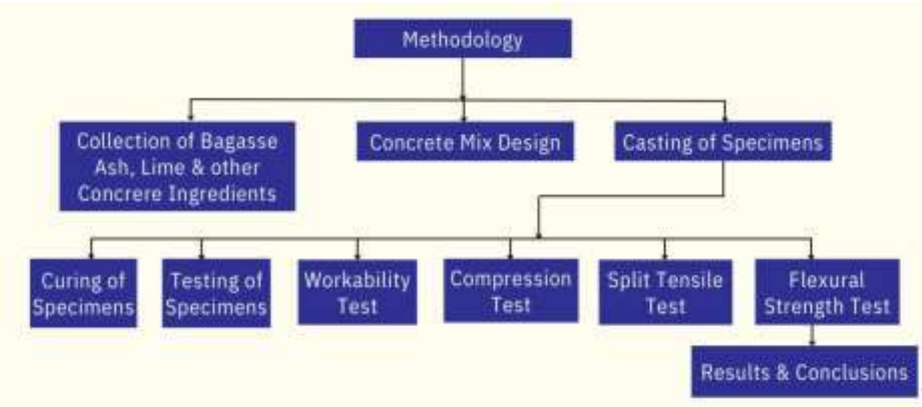

Figure 1. Research Methodology Flow char

Ingredients and Their Properties

Lime

Lime, particularly sourced as a byproduct Fertilizer plants, has diverse applications in construction, agriculture, and environmental management. Composed of calcium oxide (CaO), it is produced through the calcination of limestone, forming quicklime, which can be hydrated to form slaked lime ($Ca(OH)_2$) (Boynton 1980). Lime's effectiveness as a binding agent strengthens construction materials and improves flexibility, making it ideal for preservation work (Holmes & Wingate 2002). In concrete, lime improves workability and interacts with pozzolanic materials like bagasse ash to enhance strength and durability (Taylor 1997; Neville 2011). Its versatility makes lime a sustainable solution across industries. Table 1 show the chemical composition of lime and Figure 2 shows the wasted lime of fertilizer plants.

Table 1. Chemical properties of lime

Source	Byproduct of calcium ammonium nitrate production (fertilizer industry)

Chemical Composition	Predominantly calcium oxide (CaO)
Purity	Approximately 85-95% calcium oxide
pH	Alkaline (pH 12-13)
Density	3.3 g/cm^3
Specific Gravity	2.2-2.5
Moisture Content	<1%
Fineness	90% passing through a sieve No 200
Color	Off-white to light gray
Solubility	Slightly soluble in water (0.19 g/100 ml at 25°C)
Reactivity	High, reacts readily with water to form calcium hydroxide

Figure. 2 Lime Powder

Bagasse Ash

Bagasse ash, a byproduct of sugar mills, holds significant potential for industrial applications, particularly in construction. Its pozzolanic properties improve the mechanical strength and durability of concrete, while enhancing resistance to chemical attacks such as sulfates and chlorides (Cordeiro et al. 2008; Ganesan et al. 2007). Additionally, using bagasse ash as a partial cement replacement reduces the environmental impact of concrete production by lowering cement demand and diverting waste from landfills (Ramez anianpour et al. 2009; Nair et al. 2006). It also improves concrete workability and reduces the heat of hydration, making it suitable for large-scale projects (Chusilp et al. 2009). Bagasse ash has further potential in agriculture by enhancing soil structure and nutrient availability (Memon et al. 2012). Overall, bagasse ash promotes sustainable construction practices and contributes to waste management and environmental preservation. The chemical composition of Bagasse Ash is presented in Table 2 and Figure 3 shows the bagasse ash produced in bulk quantity in sugar mills.

Table 3. Chemical composition of Bagasse Ash

Property	**Description/Value**
Source	Byproduct of bagasse

	combustion in sugar mills
Chemical Composition	Rich in silica (SiO_2), alumina (Al_2O_3), and iron oxides (Fe_2O_3)
Silica (SiO_2) Content	60-70%
Alumina (Al_2O_3) Content	5-15%
Iron Oxides (Fe_2O_3)	2-5%
Calcium Oxide (CaO)	5-10%
Magnesium Oxide (MgO)	1-4%
Loss on Ignition (LOI)	5-15% (indicating unburnt carbon)
Density	2.2-2.4 g/cm^3
Fineness	75-80% passing through a sieve No 200

Specific Gravity	2.1-2.3
Color	Gray to dark gray
pH	Alkaline (pH 9-10)
Pozzolanic Activity	High, reacts with calcium hydroxide to form cementitious compounds

Figure. 3 Sample of Bagasse Ash

Coarse Aggregate

The coarse aggregate used in this study is 19mm Sakhi Sarwar crush, known for its angular shape, which improves interlocking and enhances the strength of the concrete, all physical properties of coarse aggregates are represented in table 4. Several tests were performed on the aggregate, including the Los Angeles Abrasion Test, which yielded a value of 18.16%, indicating good hardness and wear resistance.

Table 4. Physical properties of coarse aggregates

Physical Property	**Coarse Aggregate**
Source	Sargodha Crush
Max. Size	19mm
Fineness Modulus	6.85
Specific Gravity	2.53 (SSD)
Water Absorption	0.6%
Impact Value	7.1%
Crushing Value	21.33%
Los Angeles Abrasion	18.16%
Air Void %	0.50%
Compressive Strength	19.8 Mpa
Average Unit Weight	1680 Kg/m^3

Fine Aggregate

The fine aggregate used was riverbed-derived harrow sand, selected for its smooth, well-rounded grains. It contributes to the workability of the concrete and helps in reducing shrinkage and cracking, all physical properties of fine aggregates are represented in table. 5 . The fineness modulus of the sand was calculated to be 2.56, indicating its suitability for concrete mixes

Table 5. Physical properties of fine aggregates

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Source	**Harrow Sand**
Fineness Modulus	2.56
Specific Gravity	2.65 (SSD)
Water Absorption	1.32%
Loose Bulk Density	1.64g/cm^3
Compacted Bulk Density	1.74g/cm^3

Materials Testing

Fineness Modulus of Sand

The fineness modulus of sand was calculated using traditional sieve analysis as per ASTM C136. The modulus was determined to be 2.65, which aligns with ACI 211.1 recommendations for sand used in concrete.

Specific Gravity and Water Absorption of Sand

. These properties were determined using the procedures outlined in ASTM C128, providing essential data for mix design. The specific gravity of sand was calculated as 2.65, with a water absorption of 1.32%.

Unit Weight of Sand

. This measurement helps determine the density of the sand, which is vital for mix design and achieving the correct proportions. The unit weight of sand was tested according to ASTM C29, yielding a loose bulk density of 1.64 g/cm³ and a compacted bulk density of 1.74 g/cm³.

Unit Weight of Coarse Aggregate

The unit weight test for coarse aggregate was performed as per ASTM C29, with loose bulk density determined at 1.32 g/cm³ and compacted bulk density at 1.42 g/cm³.

Los Angeles Abrasion Test of Coarse Aggregate

. The Los Angeles Abrasion test, conducted as per ASTM C131, revealed an abrasion value of 18.16%, indicating the aggregate's suitability for use in concrete with high durability requirements (ACI 211.2-98).

Specific Gravity and Water Absorption of Coarse Aggregate.

Specific gravity tests for coarse aggregate followed ASTM C127, resulting in an oven-dry specific gravity of 2.41 and SSD specific gravity of 2.53. Water absorption was calculated at 0.6%, aligning with ACI 211.1-91 guidelines.

Impact Value of Coarse Aggregate

. The impact value test was conducted according to ASTM D5874, yielding a value of 7.1%, indicating the aggregate's resistance to impact and suitability for concrete use.

Fineness Modulus of Coarse Aggregate

The Fineness Modulus of coarse aggregate was determined as 6.85, following ASTM C136. This is consistent with the aggregate size distribution recommended by ACI 211.1-91 for concrete mix design.

Sample Preparation

The study involved the preparation of 54 test specimens, including 6-inch cubes, cylinders, and beams. The two concrete mixes were prepared by replacing 5% of the cement with bagasse ash and 10% with lime and second one is 10% lime and 10% bagasse ash resulting in a 1:2:4 mix. After casting, the samples were cured for 28, 56, and 90 days, with half of them cured in an ammonium nitrate solution to simulate exposure to aggressive environments. Table 6 shows. Mixed Proportion for concrete specimens.

Table 6. Mixed Proportion for each Cube

Concrete Mix	**Cement (kg)**	**Sand (kg)**	**C. Aggregate (kg)**	**Water (kg)**	**Lime (kg)**	**Bagasse Ash (kg)**
Simple Concrete	125	250	500	783.68	70	0

Mix						
Concrete Mix with 10% Lime and 5% Bagasse Ash	30	0	0	0	0	30
Concrete Mix with 10% Lime and 10% Bagasse Ash	40	0	0	0	0	40

Testing

Slump Cone Test

The slump cone test, (ASTM C143/C143M-20) which measures the consistency and workability of the concrete, yielded a slump of 79mm. This value indicates a good balance between workability and stability, ensuring that the concrete can be properly compacted without excessive segregation.

Lime and Bagasse Ash Concrete Preparation

The preparation of lime and bagasse ash concrete involved thoroughly mixing the cement, lime, bagasse ash, aggregate, and water. The resulting concrete showed improved workability due to the lime and enhanced strength from the pozzolanic reaction of the bagasse ash.

Casting of Concrete Samples

The concrete samples were cast in molds and compacted to remove air voids and achieve the desired density. After casting, the samples were cured in a controlled environment to promote proper hydration and strength development. The control samples and lime-bagasse ash samples were prepared and cured under identical conditions to ensure accurate comparisons during testing.

Testing ages of Concrete Samples

. The compressive, split tensile, and flexural strengths of the concrete samples were tested at 28, 56, and 90 days. The results demonstrated that the addition of lime and bagasse ash improved the durability and mechanical properties of the concrete, particularly in environments containing ammonium nitrate.

Results and Discussion

Compressive Strength

The figure 4 shows the conclusion that strongest resistance to ammonium nitrate attack was shown by the 20% replacement ratio in ammonium nitrate ($NH3NO_3$), which showed the least decline in compressive strength, at a decrease of 15.11%. Among the studied samples, the 0% replacement ratio had the largest loss, measuring 33.04%, and was the least resistant. The 15% replacement ratio shown a moderate 26.57%decline.The 15% cement replacement with 10% lime and 5% bagasse ash consistently outperforms other samples in water curing. Conversely, the 20% cement replacement with 10% lime and 10% bagasse ash exhibits the least strength reduction among all samples during ammonium nitrate curing. This suggests that the optimal cement replacement for maximum strength and resistance against ammonium nitrate attack depends the balance between cement, lime, and bagasse ash. The superior performance of the 15% and 20% samples can be attributed to factors such as pozzolanic reactions, which lead to the formation of additional calcium silicate hydrate (CSH), a strength-enhancing gel. Additionally, the filler effect of pozzolanic materials contributes to a denser microstructure, and the reduced water demand can result in a stronger concrete and resistance to ammonium nitrate attack.

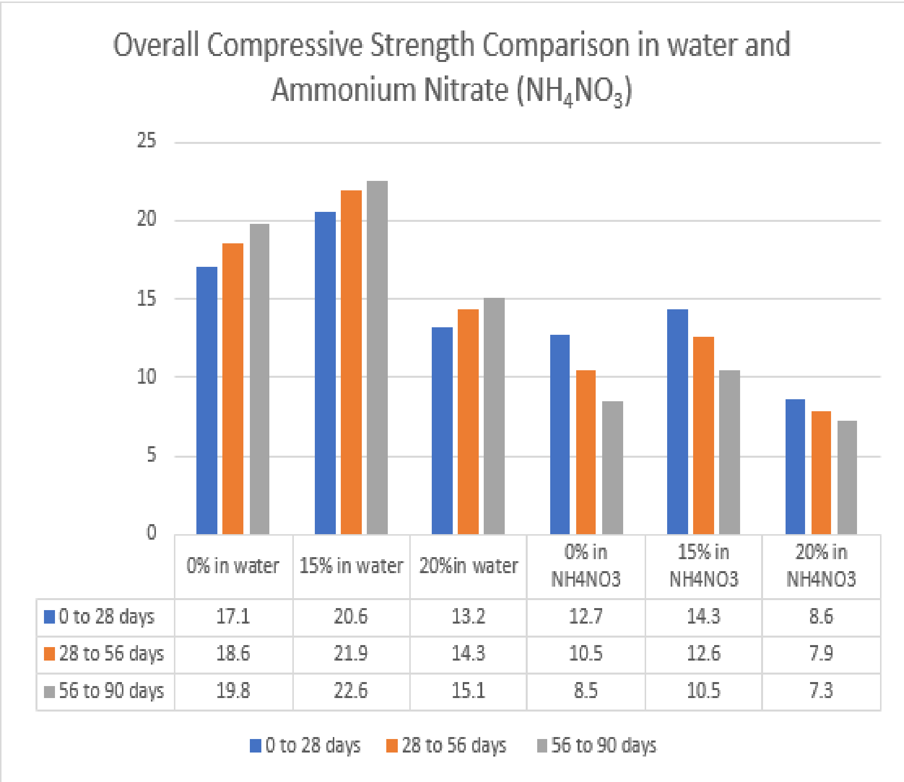
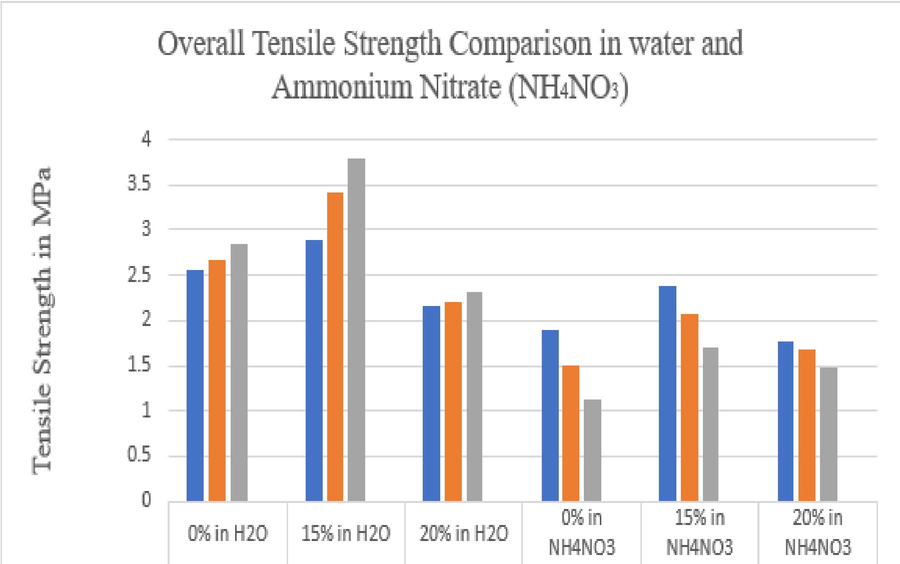


Figure. 4 Compressive Strength of concrete cured in drinking water and Ammonium Nitrate

Splitting Tensile Strength

The figure 5 illustrates conclusion, the tensile strength reduction across different replacement ratios in ammonium nitrate (NH_4NO_3) revealed that the 20% replacement ratio showed the least degradation, with a 15.91% reduction in strength over time, indicating the highest resistance to ammonium nitrate attack. The 15% replacement ratio experienced a moderate

28.57% reduction, while the 0% replacement ratio suffered the most significant loss, with a 40.21% decrease in tensile strength, making it the least resistant to ammonium nitrate. The 15% cement replacement with lime and bagasse ash consistently outperforms other samples in water curing, while the 20% replacement shows the least strength reduction in ammonium nitrate. This suggests that the optimal replacement level depends on the curing environment. Pozzolanic reactions, microstructural changes, chemical interactions, and curing conditions likely influence these results.



	0% in H2O	15% in H2O	20% in H2O	0% in NH4NO3	15% in NH4NO3	20% in NH4NO3
0 to 28 days	2.56	2.89	2.17	1.89	2.38	1.76
28 to 56 days	2.68	3.42	2.21	1.5	2.07	1.68
56 to 90 days	2.84	3.79	2.32	1.13	1.7	1.48

Figure. 5 Splitting Tensile Strength of concrete cured in drinking water and Ammonium Nitrate

Flexural Strength

The graph in the figure 6 shows that samples with 15% replacement performs best against others by gains near to 14% increase in flexural strength during water curing while 20% replacement samples performs best with about 4 % reduction in strength when exposed to ammonium nitrate due to high silica content following by 15% replacement samples which shows strength reduction about 7% while simple samples shows reduction about 17%.The graph compares the flexural strength of concrete samples cured in water and ammonium nitrate at varying cement replacement levels. Results indicate that while increasing cement replacement generally enhances flexural strength, ammonium nitrate curing consistently leads to lower values. The 15% cement replacement with lime and bagasse ash consistently outperforms other samples in water curing, while the 20% replacement shows the least strength reduction in ammonium nitrate. This suggests that the optimal replacement level depends on the curing environment. Pozzolanic reactions, microstructural changes, chemical interactions, and curing conditions likely influence these results.

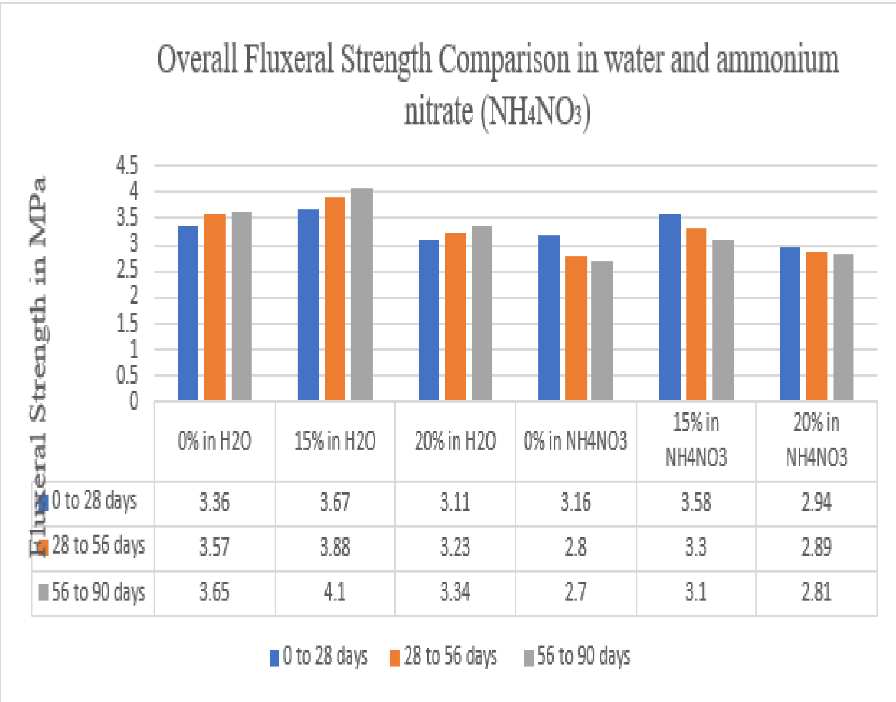


Figure 6**.** Flexural Strength of concrete cured in drinking water and Ammonium Nitrate

Conclusion and Recommendations

This study investigated the potential of using sugarcane processing byproducts, specifically bagasse ash and lime, as partial cement substitutes in concrete. The primary aim was to enhance the mechanical properties of concrete while promoting sustainable construction practices.

Strength Increase: The research revealed that replacing 15% of cement with a combination of 5% bagasse ash and 10% lime led to a significant increase in compressive, split tensile, and flexural strengths. However, increasing the replacement ratio to 20% resulted in decreased strength. These results underscore the viability of bagasse ash and lime as sustainable alternatives in concrete production. Further research is necessary to optimize the replacement ratios and investigate the long-term durability of such concrete.

Resistance against Ammonium Nitrate Attack.: The study also found that while a 15% replacement offered improved strength and moderate resistance to ammonium nitrate attack, the 20% replacement demonstrated superior resistance to this chemical attack. This indicates a trade-off between overall strength and resistance to specific chemical attacks, necessitating further research to achieve an optimal balance.

Durability: The inclusion of bagasse ash and lime enhanced the durability of the concrete. The reactive silica and alumina in bagasse ash interacted with lime to form a robust binding agent, thereby improving the concrete's resistance to corrosion, abrasion, and chemical attacks.

Workability: Additionally, the use of bagasse ash and lime improved the workability of the concrete mix. Lime increased the plasticity of the mix, making it easier to handle, while bagasse ash acted as a filler, reducing water demand and improving the mix's overall consistency.

In conclusion, the partial replacement of cement with bagasse ash and lime not only enhances the mechanical properties and durability of concrete but also contributes to environmental sustainability by reducing waste and lowering greenhouse gas emissions.

Recommendations

Optimal Replacement Ratios: A 15% partial replacement of cement with bagasse ash and lime is recommended for concrete production, as it offers improved strength, durability, and resistance to chemical attacks.

Further Research: Additional studies are needed to optimize the replacement ratios for specific applications and to explore the long-term durability of such concrete mixtures under various environmental conditions.

Practical Applications: The use of bagasse ash and lime in concrete should be further promoted as a sustainable construction practice that not only reduces waste but also enhances the mechanical properties of concrete.

Cost-Effectiveness and Sustainability: The environmental and economic benefits of using these supplementary cementitious materials should be emphasized, as they contribute to a circular economy in the construction industry.

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