A Comparative Assessment of Mechanical Properties of Lime Pozzolana Concrete Activated by Sodium Silicate Gel

Parasa Lakshmi Naga Saroja[1*], Dr. B.Vijaya Saradhi[2*]

1 Research Scholar, Department of Civil Engineering, College of Engineering, Andhra University, Visakhapatnam 530 003, India.*
1 Assistant Professor, Department of Civil Engineering, Seshadri Rao Gudlavalleru Engineering College, Gudlavalleru 521 356, India.*
2 Professor, Department of Civil Engineering, College of Engineering, Andhra University, Visakhapatnam 530 003, India.*
1 Corresponding author e-mail: lakshminagasaroja.parasa@gmail.com*

KEYWORDS
Hydraulic Lime, Fly ash, Sodium silicate gel, Lime Pozzolana Concrete, Normal water curing, Wet Hessian curing, Sustainability.

ABSTRACT

Concrete is a fundamental material in construction, second only to water in its widespread use. However, cement production—a key component of concrete—significantly contributes to global carbon dioxide (CO_2) emissions, exacerbating environmental pollution, global warming, and climate change. The cement manufacturing process is highly energy-intensive and releases substantial CO_2 due to the chemical conversion of limestone into clinker. Researchers are exploring sustainable alternatives such as hydraulic lime, fly ash, and sodium silicate gel. These materials serve as effective chemical activators in the formation of lime pozzolana concrete, which offers a more eco-friendly solution by substantially reducing CO_2 emissions associated with cement production. In this study, a specific mix design ratio of lime pozzolana concrete, in accordance with the relevant Indian Standard (IS) code, was selected for structural-grade concrete. The specimens underwent curing using the normal water and wet hessian method to promote the hydration of cementitious materials and strength development. Mechanical properties, including compression, split tension, and flexure strengths, were evaluated at 7, 28, 56, 90 and 180 days. The test results of specimens that underwent normal water curing gave better strength results when compared with the wet hessian curing method and met the strength requirements specified in the IS code, demonstrating the feasibility of lime pozzolana concrete as a sustainable alternative to conventional cement-based concrete

1. Introduction

The excessive release of carbon dioxide (CO_2) has been identified as a significant contributor to environmental pollution. Among the various industries responsible for greenhouse gas emissions, the construction sector stands out as one of the most detrimental. Studies indicate that emissions from this industry can reach up to 50% of total greenhouse gases [1]. A key factor in this issue is the production of cement, which is recognized as a major source of CO_2 emissions. For every ton of cement manufactured, an approximately equal amount of CO_2 is released into the atmosphere. Furthermore, cement plants are known for their high energy consumption and the generation of large quantities of undesirable by-products, which pose severe environmental challenges [2].

To address these concerns, cement manufacturers are increasingly adopting sustainable practices, such as blending or intergrinding mineral additives like slag, natural pozzolana, sand, and limestone. These additions help reduce energy consumption and CO_2 emissions while maintaining or even enhancing production efficiency [3].

Extensive research has demonstrated that natural pozzolana is widely used as a partial replacement for Portland cement in various applications due to its numerous benefits. These advantages include cost reduction, lower heat evolution during hydration, reduced permeability, and enhanced chemical resistance [4]. Pozzolanic materials, whether of natural or artificial origin, must possess a high content of amorphous silica and a large specific surface area to initiate a strong pozzolanic reaction. In recent years, the reutilization of industrial and agricultural waste materials with pozzolanic properties has gained momentum. These materials not only serve as effective cementitious components but also offer a sustainable alternative with significant environmental benefits [4].

Another promising approach in sustainable concrete production is the use of hydraulic lime as a binder. This method is particularly relevant in applications where moderate mechanical strength is required, rather than extremely high strength. The mechanical properties of hydraulic lime binders can be enhanced by incorporating pozzolanic materials, which facilitate the formation of calcium silicate hydrates through their reaction with lime (calcium hydroxide) in the presence of water. This process contributes to the development of more eco-friendly binders with lower CO_2 emissions, making it a viable alternative in sustainable construction practices [5].

Additionally, alkali activation has emerged as a rapidly advancing field of research and development in the global construction industry. The commercial-scale implementation of alkali-activated cements and concretes is now progressing swiftly in multiple countries [6]. This paper explores the technical feasibility of producing alkali-activated lime-pozzolana concrete using sodium silicate gel, hydraulic lime, and fly ash as binders. The study further evaluates the mechanical properties of the resulting concrete and its sustainability, highlighting its potential as an innovative and environmentally friendly construction material.

2. Rationale of the Study

The primary limitation of using lime and fly ash in concrete is the slow reaction process, which delays early strength development and results in longer curing times. To address this challenge, a preliminary experimental study on hydraulic lime mortars was conducted, demonstrating the feasibility of producing high-strength lime-based mortars. By incorporating sodium silicate gel with hydraulic lime and fly ash, it is possible to achieve compressive strength at 28 days comparable to that of ordinary Portland cement concrete. This research focuses on the mechanical properties of lime pozzolana concrete (LPC), aiming to identify optimal blends of hydraulic lime, pozzolans, and sodium silicate gel to develop structural-grade concrete.

3. Materials and Methods

3.1 Materials

For construction applications, lime must contain at least 60% calcium oxide. High-purity hydraulic lime, typically ranging from 75% to 95% purity, is widely used in construction as per IS 712:1984 and IS 6932:1973. When calcium oxide in lime reacts with atmospheric carbon dioxide, it forms calcium carbonate, effectively sealing microcracks and enhancing structural durability. The hydraulic lime used in this study was sourced from Sri Sai Venkata Teja Chemicals, Piduguralla, with a purity of 92% and a specific gravity of 2.2. Fly ash was collected from VTPS-Ibrahimpatnam, with a specific gravity of 2.89. Sodium silicate gel was procured from Lakshmi Chemicals, Vijayawada, as it promotes the reaction between lime and fly ash, improving concrete hardening. Locally available river sand, conforming to Zone II specifications, was used as fine aggregate. Its properties, determined as per relevant IS codes, include: Specific gravity: 2.68, Fineness modulus: 3.3, Moisture content: 7.8% and Water absorption: 8%. The coarse aggregate consisted of locally sourced crushed stone, comprising 60% of 20 mm-sized aggregate and 40% of 10 mm-sized aggregate [7]. Its properties, as per IS code standards, include: Specific gravity: 2.78, Fineness modulus: 7, Moisture content: 2% and Water absorption: 2.6%. Water plays a crucial role in concrete hydration and strength development. The water used in this study met the quality requirements specified in IS 456:2000.

3.2 Methodology

Mix proportion, 1:1:2 (LP20), was selected based on IS 5817:1992 recommendations. Extensive trial mixes were conducted for this ratio to determine optimal material variations for structural-grade concrete. The hydraulic lime content was adjusted in 5% increments up to 35%, while sodium silicate was varied in 7.5% increments up to 52.5%, with the remaining portion consisting of fly ash. All concrete mixes were prepared with a compaction factor of 0.85±0.01. Workability was evaluated using compaction factor and slump cone tests, as per IS code specifications. Specimens were cast in steel molds in the following dimensions: Cube specimens: 150 mm × 150 mm × 150 mm, Cylindrical specimens: 150 mm diameter × 300 mm height and Beam specimens: 500 mm × 100 mm × 100 mm. Three specimens were cast per set, with six samples for each mix, following IS 516:2021 guidelines. After demolding, the specimens underwent wet hessian and normal water curing for approximately 7, 28, 56, 91 and 180 days. Wet hessian curing, as recommended by IS 5817:1992, ensures continuous moisture supply, which is essential for proper hydration and carbonation. This curing method offers several advantages, including: Prevention of cracking, Improved strength and durability, Enhanced workability, Cost-effectiveness and environmental sustainability. Due to these benefits, wet hessian curing is particularly suitable for heritage restoration [7] and lime-pozzolana concrete applications. Normal water curing is suitable for flyash based concrete which increases the strength of concrete after later ages, prevents cracking, increases the durability of concrete [8].

3.2.1 Mix Notations

The LP20WM0 and LP20NM0 mixes consisted of 20% hydraulic lime and 80% fly ash subjected to wet hessian and normal water curing. Similarly, the SLP20 mixes followed the same composition pattern but incorporated sodium silicate in 7.5% increments up to 52.5%, with hydraulic lime increasing in 5% increments up to 35%, and the remaining portion comprising fly ash. These variations were designated SLP20WM1 to SLP20WM7 and SLP20NM1 to SLP20NM7 for wet hessian and normal water curing methods respectively.

4. Results and Discussion

4.1 Compressive Strength

The compressive strength test was conducted in accordance with IS 516:2021. Experimental findings revealed that the highest strength was achieved in SLP20NM5. Among the seven mix variations of SLP20WM and SLP20NM, all exhibited greater compressive strength compared to their conventional LPW20 and LPN20 counterparts. This improvement is attributed to the inclusion of sodium silicate gel, which functions as a chemical activator, enhancing the reaction between the silica in fly ash and calcium in hydraulic lime.

During the hydration process, silica and aluminates from fly ash react with calcium from hydraulic lime, forming calcium silicate hydrate (C-S-H) and calcium aluminate silicate hydrate (C-A-S-H) gels [9]. These compounds contribute to concrete hardening, improved strength development, and a denser microstructure with reduced porosity. Additionally, the SLP20 mix demonstrated superior performance compared to SLP40, likely due to its higher content of cementitious material.

An increase in hydraulic lime content to 20-25% and sodium silicate gel to 30-37.5% led to improved compressive strength, as depicted in Figures 1 to 4. The compressive strength variations for the SLP20WM1 to SLP20WM7 mixes were recorded as follows: +64.48, +23.59, +22.47, +14.99, +12.93, -21.24, and -5.86% at 7 days; +32.46, +23.30, +27.57, +15.05, +14.39, -20.88, and -6.84% at 28 days; +35.43, +22.63, +26.29, +12.77, +15.76, -20.61, and -6.84% at

56 days; +39.23, +23.08, +23.28, +12.76, +15.14, -20.36, and -6.15% at 91 days; and +42.30, +21.92, +21.82, +12.66, +14.59, -19.79, and -6.39% at 180 days. Similarly, the SLP20NM1 to SLP20NM7 mixes exhibited variations of +62.61, +24.42, +22.35, +13.93, +12.85, -20.86, and -4.83% at 7 days; +25.93, +22.40, +27.25, +14.74, +14.22, -20.63, and -6.80% at 28 days; +25.72, +23.11, +26.53, +13.41, +14.58, -21.00, and -6.67% at 56 days; +27.80, +23.54, +23.54, +12.61, +14.98, -20.48, and -6.48% at 91 days; and +31.34, +21.79, +22.66, +12.12, +14.59, -20.04, and -6.52% at 180 days.

Additionally, the compressive strength of the SLP20WM1 to SLP20WM7 mixes was observed to be 1.00, 1.64, 2.03, 2.49, 2.86, 3.23, 2.55, and 2.40 times that of LP20WM0 at 7 days; 1.32, 1.63, 2.08, 2.40, 2.74, 2.17, and 2.02 times at 28 days; 1.35, 1.66, 2.10, 2.37, 2.74, 2.17, and 2.03 times at 56 days; 1.39, 1.71, 2.11, 2.38, 2.74, 2.18, and 2.05 times at 91 days; and 1.42, 1.73, 2.11, 2.38, 2.73, 2.19, and 2.05 times at 180 days. Similarly, for the SLP20NM1 to SLP20NM7 mixes, the strength values were 1.63, 2.02, 2.48, 2.82, 3.18, 2.52, and 2.40 times at 7 days; 1.26, 1.54, 1.96, 2.25, 2.57, 2.04, and 1.90 times at 28 days; 1.26, 1.55, 1.96, 2.22, 2.54, 2.01, and 1.88 times at 56 days; 1.28, 1.58, 1.95, 2.20, 2.53, 2.01, and 1.88 times at 91 days; and 1.31, 1.60, 1.96, 2.20, 2.52, 2.02, and 1.88 times at 180 days, compared to LP20NM0.

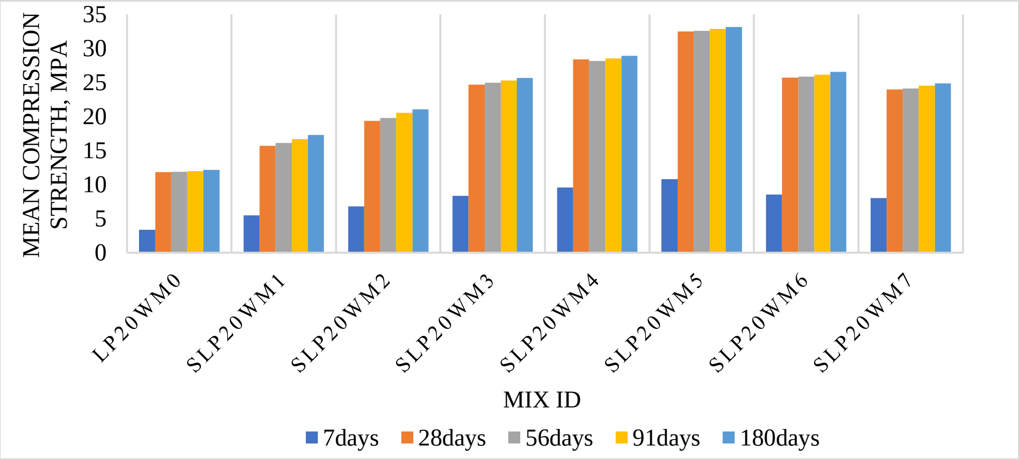

Fig 1. Mean compression strength vs. Mix ID illustrates wet hessian curing

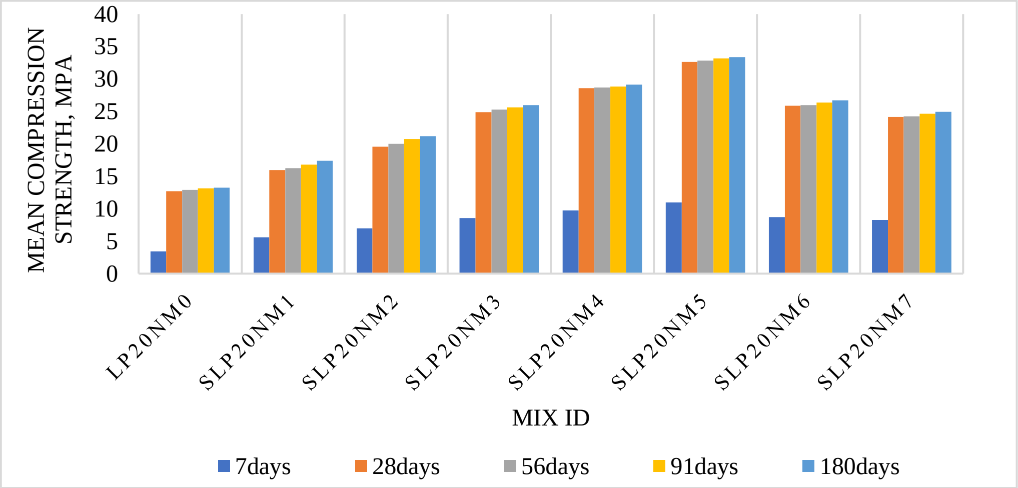

Fig 2. Mean compression strength vs. Mix ID illustrates normal water curing

4.2 Split tension strength

A similar trend was observed for split tensile strength, as shown in Figures 3 and 4. The split tensile strength variations for the SLP20WM1 to SLP20WM7 mixes were +96.77, +22.95, +22.67, +14.13, +13.33, -21.01, and -6.38% at 7 days; +58.72, +23.12, +27.70, +15.07, +14.38, -20.95, and -6.71% at 28 days; +133.46, +22.63, +26.29, +12.77, +15.76, -20.61, and -6.84% at 56 days; +135.23, +23.08, +23.28, +12.76, +15.14, -20.36, and -6.15% at 91 days; and +134.80, +21.92, +21.82, +12.66, +14.59, -19.79, and -6.39% at 180 days. Likewise, for the SLP20NM1 to SLP20NM7 mixes, the variations were +103.23, +23.81, +24.36, +10.34, +13.05, -21.00, and -4.83% at 7 days; +38.41, +24.02, +27.52, +12.95, +14.33, -20.67, and -6.60% at 28 days; +38.40, +23.11, +26.04, +13.85, +13.52, -20.27, and -6.11% at 56 days; +42.75, +21.93, +23.56, +12.88, +14.47, -20.31, and -6.48% at 91 days; and +46.21, +20.72, +21.90, +12.83, +13.91, -19.18, and -5.42% at 180 days.

Moreover, the split tensile strength of the SLP20WM1 to SLP20WM7 mixes was 1.97, 2.42, 2.97, 3.39, 3.84, 3.03, and 1.44 times that of LP20WM0 at 7 days; 1.59, 1.95, 2.50, 2.87, 3.28, 2.60, and 1.53 times at 28 days; 2.33, 2.86, 3.62, 4.08, 4.72, 3.75, and 1.50 times at 56 days; 2.35, 2.90, 3.57, 4.02, 4.63, 3.69, and 1.47 times at 91 days; and 2.35, 2.86, 3.49, 3.93, 4.50, 3.61, and 1.44 times at 180 days. Similarly, for the SLP20NM1 to SLP20NM7 mixes, the values were 2.03, 2.52, 3.13, 3.45, 3.90, 3.08, and 1.44 times at 7 days; 1.38, 1.72, 2.19, 2.47, 2.83, 2.24, and 1.51 times at 28 days; 1.38, 1.70, 2.15, 2.44, 2.78, 2.21, and 1.50 times at 56 days; 1.43, 1.74, 2.15, 2.43, 2.78, 2.21, and 1.45 times at 91 days; and 1.46, 1.77, 2.15, 2.43, 2.77, 2.23, and 1.45 times at 180 days, compared to LP20NM0.

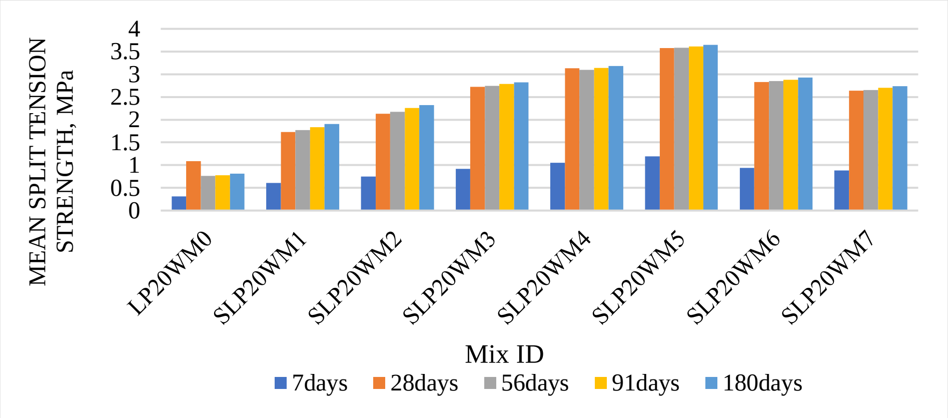

Fig 3. Mean split tension strength vs. Mix ID illustrates wet hessian curing

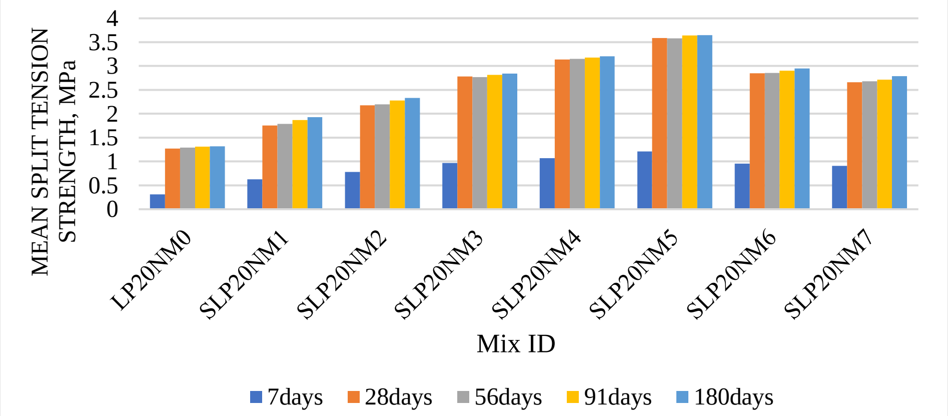

Fig 4. Mean split tension strength vs. Mix ID illustrates normal water curing

4.3 Flexural Strength

The flexural strength test was also carried out following IS 516:2021 standards. The results demonstrated a pattern consistent with the compressive strength and split tension strength outcomes. The inclusion of hydraulic lime contributed to improved flexural performance of the concrete [7]. Figures 5 and 6 present the test results.

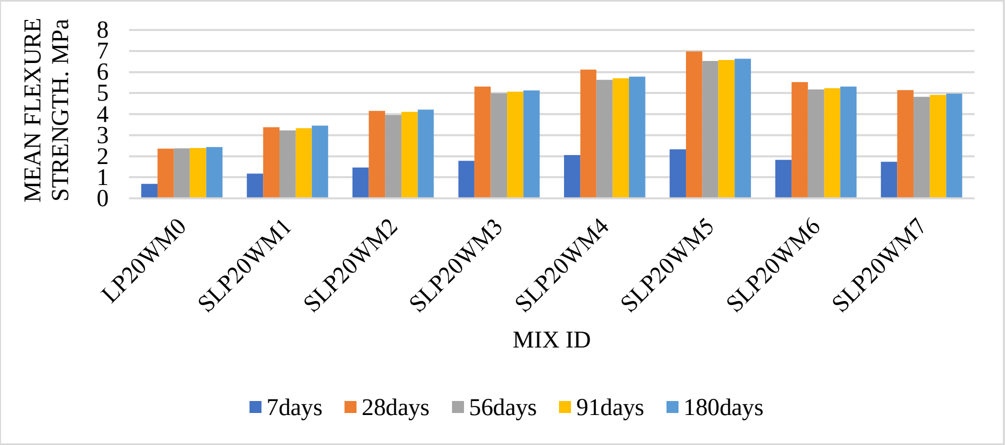

Fig 5. Mean flexure strength vs. Mix ID illustrates wet hessian curing

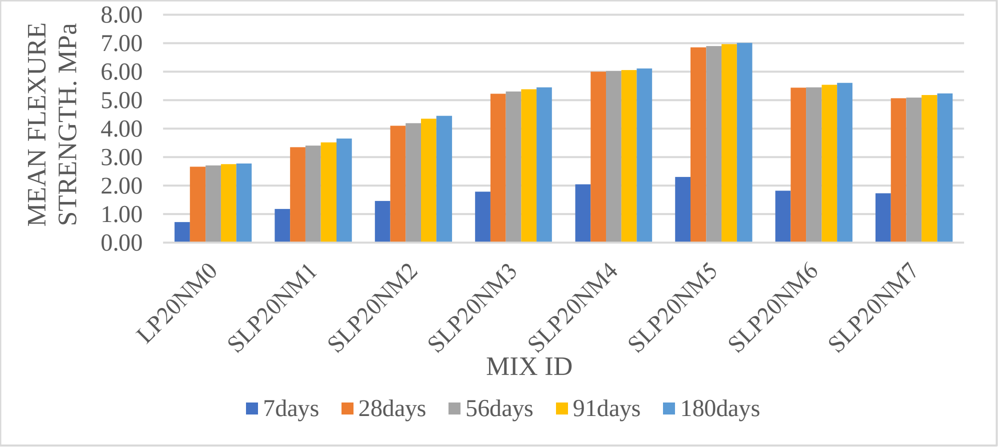

Fig 6. Mean flexure strength vs. Mix ID illustrates normal water curing

5. Recommendations

This study evaluates the strength development of lime pozzolana concrete (LPC) using hydraulic lime, fly ash, and sodium silicate gel as cementitious materials. It is recommended to explore the use of locally available pozzolanic materials as potential alternatives to assess their impact on concrete strength characteristics. Additionally, further research can be conducted on other chemical activators to enhance the sustainability and performance of LPC.

6. Conclusions

The addition of sodium silicate gel as a chemical activator significantly improves the strength of lime pozzolana concrete (LPC). The pozzolanic reaction between calcium, silica, and alumina leads to the formation of calcium silicate hydrate (C-S-H) and calcium aluminate silicate hydrate (C-A-S-H) gels, which contribute to strength development. The SLP20NM5 mix, containing 25% hydraulic lime and 37.5% sodium silicate gel, exhibited superior mechanical performance compared to the SLP20WM5 mix with the same proportions, as well as the LP20WM0 and LP20NWM0 mixes. This improvement is attributed to the higher concentration of cementitious materials, which enhances hydration product formation in addition to carbonation processes [10], reduces porosity, and results in a denser concrete structure. Moreover, incorporating sodium silicate gel supports sustainable construction practices by offering an eco-friendly solution that reduces greenhouse gas emissions while maintaining structural integrity in various applications.

7. Acknowledgments

The authors express their sincere gratitude to the Department of Civil Engineering, Seshadri Rao Gudlavalleru Engineering College, Gudlavalleru, for providing the necessary infrastructure and facilities that enabled the successful completion of this experimental study.

8. References

1. Ji Min, Gongxing Yan, AzherM. Abed, Samia Elattar, Mohamed Amine Khadimallah, Amin Jan, H. Elhosiny Ali (2022) The effect of carbon dioxide emissions on the building energy efficiency. Fuel. 326:124842. https://doi.org/10.1016/j.fuel.2022. 124842
2. Sohaib Nazar, Jian Yang, Muhammad Ashraf, Fahid Aslam, Muhammad Faisal Javed, Sayed M. Eldin, Jianhe Xie (2023). Formulation and characterization of cleaner one-part novel fly ash/lime-based alkali-activated material. J. of Mat. Res and Tech. 23:3821-3829. https://doi.org/10.1016/j.jmrt.2023.02.022
3. Ramalingam Malathy, Ragav Shanmugam, Deepalakshmi Dhamotharan, Dhivya Kamaraj, Ma yakrishnan Prabakaran, Jongpil Kim (2023) Lime based concrete and mortar enhanced with pozzolanic materials – State of art. Constr. Build. Mater. 390:131415 https://doi.org/10.1016/j.conbuildmat.2023.131415
4. M. Ghrici, S. Kenai, M. Said-Mansour (2007) Mechanical properties and durability of mortar and concrete containing natural pozzolana and limestone blended cements Cem. Concr. Compos. 29(7):542-549. https://doi.org/10.1016/j.cemconcomp.2007.04.009
5. Ana L. Velosa, Paulo B. Cachim. (2009) Hydraulic-lime based concrete: strength development using a pozzolanic addition and different curing conditions. Construction Buildings Materials. 23(5):2107-2111. https://doi.org/10.1016/j.conbuildmat.2008.08. 013
6. J.L. Provis, A. Palomo, C. Shi (2015) Advances in understanding alkali-activated materials. Cement Concr Res. 78:110-125. https://doi.org/10.1016/j.cemconres.2015. 04.013
7. Nikhil Kumar Degloorkar, Rathish Kumar Pancharathi (2022) Use of particle packing methods for development of lime fly ash-based mortars for repair of heritage structures. Mater. Today: Proc. 61(2):123-131. https://doi.org/10.1016/j.matpr.2021.06.019
8. David O. Koteng, Chun-Tao Chenet al. (2015) Strength development of lime-pozzolana pastes with silica fume and fly ash. Constr. Build. Mater. 84:294-300. https://doi.org/10.1016/j.conbuildmat.2015.03.052
9. E.R. Grist, K.A. Paine, A. Heath, J. Norman, H. Pinder. (2015) Structural and durability properties of hydraulic lime–pozzolan concretes. Cem. Concr. Compos. 62: 212-223. https://doi.org/10.1016/j.cemconcomp.2015.07.001
10. K. Mohammed Haneefa, S. Divya Rani, R. Ramasamy, Manu Santhanam. (2019) Microstructure and geochemistry of lime plaster mortar from a heritage structure. Constr. Build. Mater. 225:538-554. https://doi.org/10.1016/j.conbuildmat.2019.07.159
11. IS 5817:1992- Preparation and use of lime-pozzolana mixture concrete in buildings and roads-code of practice. Bur. Indian Std., New Delhi.
12. IS 712:1984- Specification for building lime. Bur. Indian Std., New Delhi
13. IS 6932:1973- Methods of tests for building lime. Bur. Indian Std., New Delhi
14. IS 3812:2003- Pulverized fuel ash – specification. Bur. Indian Std., New Delhi
15. IS 456-2000: Indian Standard Plain and Reinforced Concrete Code of Practice. Bur. Indian Std., New Delhi
16. IS:383-1970: Specification for coarse and fine aggregates from natural sources for concrete. Bur. Indian Std., New Delhi
17. IS 2386 (part3) - 1963: Methods of test for aggregates for concrete. Bur. Indian Std., New Delhi
18. IS 516:2021- Hardened concrete – methods of test. Bur. Indian Std., New Delhi