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INFLUENCE OF NANO SILICA ON MECHANICAL AND DURABILITY PROPERTIES OF GEOPOLYMER CONCRETE

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ABSTRACT
The growing demand for sustainable construction materials has led to increased interest in geopolymer concrete (GPC) as a potential alternative to conventional Portland cement concrete. Geopolymer concrete, primarily synthesized from industrial by-products such as fly ash or slag, offers reduced carbon emissions and enhanced thermal and chemical resistance. This study investigates the influence of nano silica (NS) incorporation on the mechanical and durability properties of geopolymer concrete. Nano silica, due to its high surface area and pozzolanic reactivity, is known to enhance the microstructure and densification of cementitious materials. Various dosages of nano silica were introduced into the geopolymer matrix to evaluate their effects on compressive strength, tensile strength, and flexural strength, along with durability characteristics such as resistance to acid attack, water absorption, and chloride ion penetration. The results indicate that optimal nano silica content significantly improves both mechanical performance and durability parameters, mainly through microstructural refinement, improved geopolymer gel formation, and reduced porosity. This study underscores the potential of nano silica as an effective additive to enhance the performance and sustainability of geopolymer concrete for advanced construction applications.

Keywords:
Geopolymer Concrete, Mechanical Properties, Durability, Compressive Strength, Tensile Strength, Flexural Strength.

I. INTRODUCTION

The construction industry is under increasing pressure to adopt sustainable practices and materials that reduce environmental impact. Ordinary Portland cement (OPC), the primary binder in conventional concrete, is responsible for significant CO_2 emissions during its production. As a response, geopolymer concrete (GPC) has emerged as a promising alternative binder system, utilizing industrial by-products such as fly ash, slag, and metakaolin activated by alkaline solutions to form a durable, cement-free matrix. Geopolymer concrete offers several advantages over OPC-based concrete, including improved resistance to chemical attack, lower permeability, and enhanced thermal stability. However, challenges such as slower early-age strength development and variability in mechanical performance have limited its widespread adoption. To address these issues, researchers have explored the incorporation of nano materials, particularly nano silica (NS), into the geopolymer matrix. Nano silica, characterized by its extremely fine particle size and high pozzolanic reactivity, has the potential to significantly enhance the performance of GPC. When added in appropriate amounts, nano silica can improve the microstructure by filling voids, accelerating geopolymerization, and increasing the formation of calcium-alumino-silicate-hydrate or sodium-alumino-silicate-hydrate gels, leading to increased strength and durability. Geopolymer concrete represents an innovative and sustainable alternative to traditional Portland cement concrete. It is synthesized by activating aluminosilicate-rich industrial byproducts, such as fly ash, with alkaline solutions, forming a three-dimensional polymeric chain structure. This approach significantly reduces carbon dioxide emissions associated with cement production, aligning with global goals for environmental sustainability.

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Fly ash, a byproduct of coal combustion in thermal power plants, serves as a primary source material in geopolymer concrete due to its high silica and alumina content. However, one of the challenges associated with geopolymer concrete is its relatively slow strength gain at ambient temperatures and lower early-age mechanical performance. To address these limitations, the incorporation of nanosilica has emerged as a promising solution. Nanosilica, due to its high surface area and pozzolanic activity, enhances the geopolymerization process, refines the microstructure, and improves both early and long-term strength. It also reduces porosity and increases the durability of the composite material. This study explores the synergistic effects of fly ash-based geopolymer concrete blended with nanosilica, aiming to improve its mechanical and durability properties for structural applications. The integration of nanotechnology into geopolymer systems represents a cutting-edge development in sustainable construction materials.

II. MATERIALS

In this study, geopolymer concrete was developed using Class F fly ash as the primary binder, with nanosilica incorporated as a partial replacement at 1%, 2%, and 3% by weight of the fly ash. The fly ash, sourced from a nearby thermal power plant, was gray in color with a specific gravity ranging from 2.2 to 2.4 and a fineness of less than 45 µm. It contained major oxides such as SiO_2 (50–60%), Al_2O_3 (20–30%), Fe_2O_3 (5–10%), and CaO (<10%), making it a suitable aluminosilicate source for geopolymerization due to its pozzolanic nature and fine particles. Sodium hydroxide solution, prepared by dissolving ≥98% pure NaOH pellets in distilled water, served as the alkaline activator. The solution, typically with a molarity of 10 M and a specific gravity around 1.4, was cooled to room temperature before mixing. Due to its highly exothermic dissolution and high alkalinity (pH >13), strict safety precautions were observed during preparation. Nanosilica, added to enhance the concrete's performance, consisted of amorphous silica nanoparticles with an average size of 20–30 nm, specific surface area of 150–200 m²/g, and specific gravity of 2.2–2.3. Its inclusion improved mechanical strength, reduced permeability, refined pore structure, and supported early-age performance by acting as a nucleation site for geopolymer gel. River sand was used as the fine aggregate, conforming to Zone II of IS 383:2016, with a specific gravity of 2.6, fineness modulus of 2.7, water absorption of 1.5%, and a maximum particle size of 4.75 mm. Crushed angular granite in equal proportions of 10 mm and 20 mm was used as coarse aggregate, having a specific gravity of 2.7, water absorption of 0.8%, and bulk density ranging between 1500–1600 kg/m³. Potable tap water (pH ~7.0) was utilized for preparing the sodium hydroxide solution and for cleaning purposes.

Component	Raito (by volume)	Quantity(per 1m³)	Unit
Fly ash	1	400	Kg
Nanosilica	1%, 2%,3%	----	Millilitres
Fine Aggregate (M-sand)	1.5	650	Kg
Coasre Aggregate	3	1200	Kg
NAOH Solution	10M	400	Gram/ litre

Table-1: mix proportions of the materials

III. RESULTS AND DISCUSSION

COMPRESSIVE TEST RESULT:

The specimens were tested in compressive strength testing machine with a gradual loading rate of 2.5 N/mm2 until the cube fails, mean compressive strength (MPa) results are illustrated in **Fig 3.1**. A gradual increase in compressive strength has been observed in Geopolymer concrete with Addition of Nano silica upto 2% then a sudden decrease of compressive strength has been observed at the addition of 3% Nano silica. shown in Fig.3.1.

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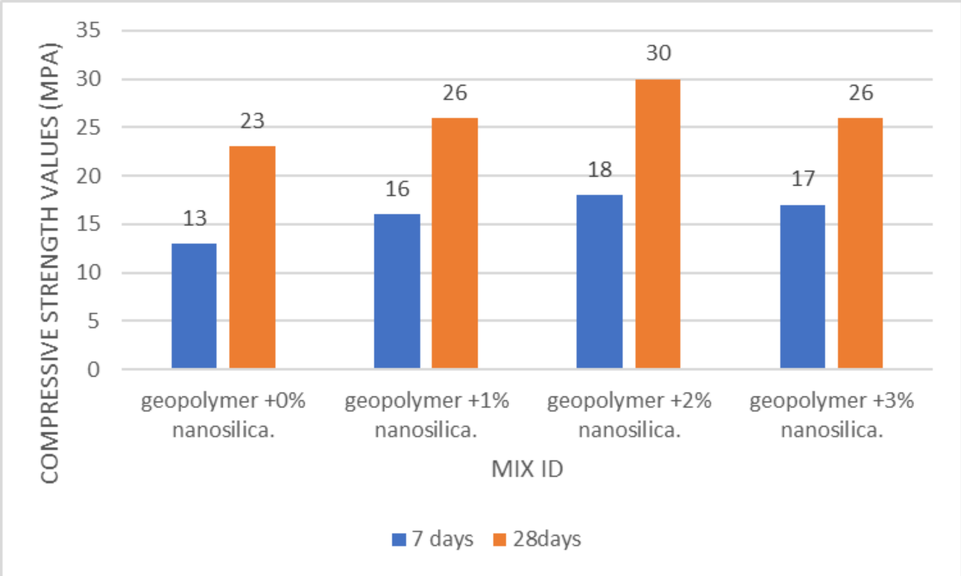

Fig 3.1 compressive strength results

Fig 3.1. shows the compressive strength of geopolymer samples with varying percentages of nanosilica (0%, 1%, 2%, and 3%) measured at two different curing periods: 7 days and 28 days. Overall, the results show that the compressive strength increases with curing time across all compositions. Among the different nanosilica contents, the addition of nanosilica up to 2% significantly enhances the strength, with the highest values observed at 2% for both 7-day and 28-day measurements. However, at 3% nanosilica, a slight reduction in strength is observed compared to 2%, suggesting a diminishing return or possible adverse effects at higher dosages. Therefore, the optimal nanosilica content for improving the compressive strength of geopolymer appears to be 2%

fig 3.2 compression test of cubes

TENSILE STRENGTH RESULT:

Split tensile strength is a key indicator of a concrete's ability to resist cracking and handle indirect tensile forces. The incorporation of nanosilica in fly ash-based geopolymer concrete enhances matrix bonding and reduces micro-porosity,which contributes to improved tensile performance**. Fig.3.3** shows the variation we have observed under the constant tensile load application after 28 days of Ambient curing.

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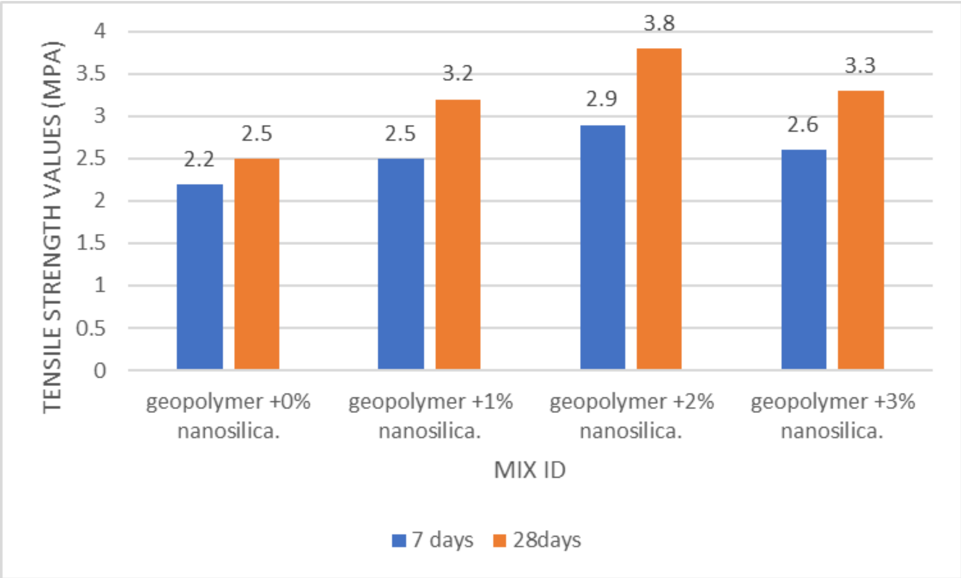

Fig 3.3. tensile strength variation

Fig 3.3. Graph presents the tensile strength of geopolymer concrete incorporating different percentages of Nano silica (0%, 1%, 2%, and 3%) measured at two curing periods: 7 days and 28 days. The results show a clear improvement in tensile strength with increased curing time across all mixes. As the nanosilica content increases from 0% to 2%, there is a steady rise in tensile strength, with the highest strength observed at 2% nanosilica for both 7-day and 28-day curing periods. This suggests that nanosilica enhances the bonding and microstructure of the geopolymer matrix, contributing to improved tensile performance. However, when the nanosilica content is increased to 3%, a slight reduction in tensile strength is noted compared to the 2% mix, indicating a possible saturation point or negative effect at higher dosages. Therefore, the optimal nanosilica content for maximizing tensile strength in geopolymer concrete appears to be 2%.

fig 3.4. Tensile strength test

WATER ABSORPTION TEST:

we have used 100mm* 100mm wooden mould in order to prepare the cubes for water absorption test and allowed them to ambient curing for 28 days.

The water absorption test is a key durability assessment that measures the amount of water a concrete sample can absorb under specific conditions. For geopolymer concrete, which relies on alkali activation rather than Portland cement hydration**,** this test plays a crucial role for the following reasons: indicator of porosity and

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permeability, Durability assessment, Quality control tool, Relation to other factors like higher compressive strength, improved freeze-thaw resistance, longer service life.

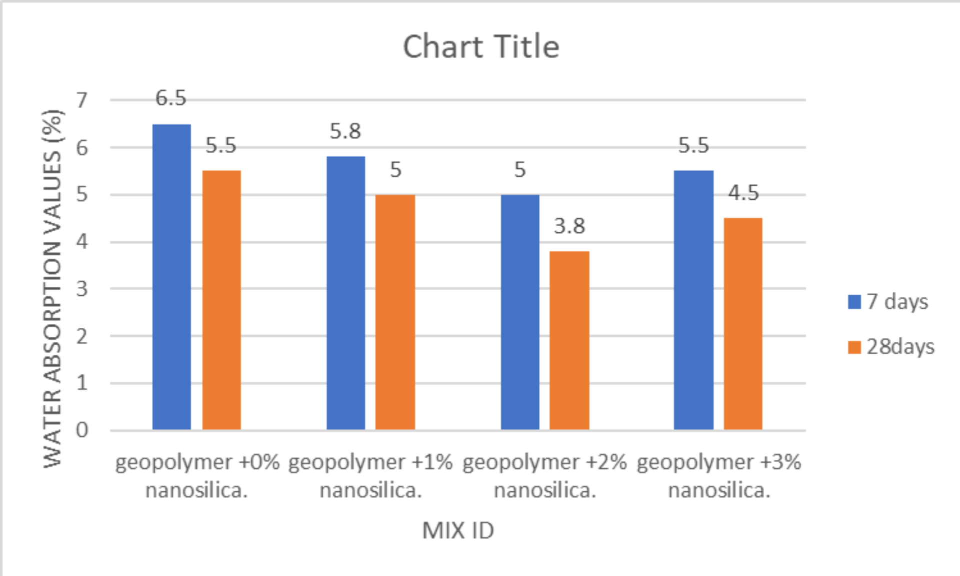

Fig 3.5. water absorption variation

Fig 3.5. The graph shows the water absorption values of geopolymer concrete with different nanosilica contents (0%, 1%, 2%, and 3%) measured at 7 days and 28 days. It can be observed that water absorption generally decreases with increasing nanosilica content up to 2%, indicating that the addition of nanosilica enhances the concrete's resistance to water penetration. However, the lowest water absorption is not significantly lower beyond 2%, suggesting a diminishing effect at higher nanosilica levels. Interestingly, the 7-day water absorption values are consistently higher than the 28-day values across all mixtures, demonstrating the benefit of extended curing in reducing porosity. Overall, the incorporation of nanosilica helps reduce water absorption, with 2% being an effective level for improving the durability of geopolymer concrete.

fig 3.6. water absorption test

FLEXURE TEST:

we have used 100*100*750 mm size of mould for the flexure test under the single point loading test (IS 516).

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and we also the reinforcement of bars with bar size of (10mm) as main bar and 8mm bars as stirrups @ spacing 90mm throughout the length.The flexure test, also known as the modulus of rupture test, is a mechanical test conducted on a concrete beam to measure its ability to resist bending or flexural stress. In this test, a beam specimen is placed on two supports and loaded at the center (single-point loading) or at two points (two-point loading) until it breaks

The flexure test mainly indiacates the following aspects: Assessment of Load-Carrying Capacity, Crack Resistance, Design Validation, Material Improvement Insight, Durability Indicator.

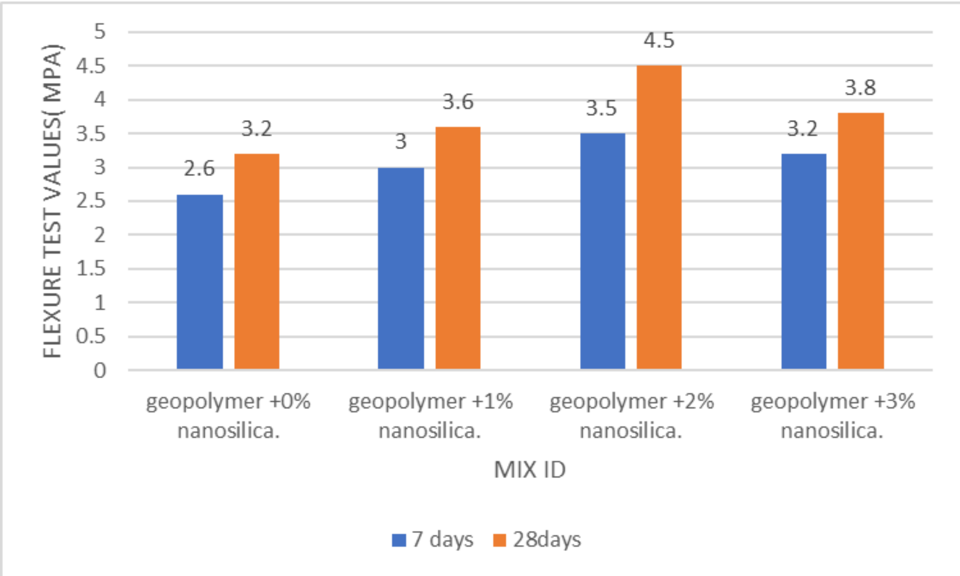

fig 3.7. flexure test results

Here the **fig 3.7.** shows The graph illustrates the flexural strength of geopolymer concrete containing varying percentages of nanosilica (0%, 1%, 2%, and 3%) at 7-day and 28-day curing periods. Overall, the flexural strength improves with increased curing time across all mixes. As the nanosilica content increases from 0% to 2%, there is a noticeable enhancement in flexural strength, with the highest value observed at 2% nanosilica for both curing periods. This indicates that nanosilica positively contributes to the development of the concrete's tensile load-bearing capacity. However, at 3% nanosilica, a slight reduction in flexural strength is seen compared to the 2% mix, suggesting that excessive nanosilica may negatively impact the material's matrix structure. Therefore, 2% nanosilica appears to be the optimal content for improving the flexural performance of geopolymer concrete.

fig 3.8. reinforcement of bar

fig.3.9. Universal testing machine

IV.CONCLUSION

We conducted four tests namely Compressive strength, Tensile strength, Water absorption & Flexure test on M20 garde of geopolymer concrete with partial replacement of nano silica as 1%,2%,3% by weight the weight of fly ash (main binder).

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Based on a series of mechanical and durability tests conducted on geopolymer concrete blended with varying percentages of nanosilica (0%, 1%, 2%, and 3%), it is evident that nanosilica plays a significant role in enhancing the overall performance of the concrete. The primary binder in this study was fly ash, and the concrete samples were subjected to ambient curing. The objective was to evaluate the effect of nanosilica on compressive strength, tensile strength, flexural strength, and water absorption.In the compressive strength test, the specimens were subjected to a gradual load of 2.5 N/mm² until failure. Results indicated that compressive strength improved progressively with the increase in nanosilica content up to 2%, after which a decline was noted at 3%. This pattern suggests that nanosilica enhances the geopolymer matrix through refined microstructure and better packing density, but excessive amounts may disrupt the matrix or cause agglomeration, leading to reduced strength.Similarly, the split tensile strength results confirmed that nanosilica enhances the bonding within the concrete, improving resistance to cracking and internal stress. Again, the highest tensile strength was recorded at 2% nanosilica, with a slight decline at 3%. This indicates a saturation point beyond which additional nanosilica no longer contributes positively to tensile performance.
Water absorption tests were also conducted to assess the durability of the concrete. Lower water absorption values indicate reduced porosity and better resistance to moisture ingress, which directly impacts the long-term durability of concrete. The test results showed a consistent decline in water absorption as nanosilica content increased up to 2%, demonstrating improved density and reduced permeability. However, similar to strength properties, the improvement plateaued beyond this point.The flexural strength test, performed using 100×100×750 mm reinforced beam specimens under single-point loading, further validated the effectiveness of nanosilica. The maximum flexural strength was observed at 2% nanosilica, indicating enhanced crack resistance and load-bearing capacity. The inclusion of reinforcement bars in the test setup also simulated realistic structural conditions, supporting the practical relevance of the results.From all the experimental observations, it is clear that nanosilica enhances the microstructure, reduces porosity, and strengthens the bonding in geopolymer concrete. However, there exists an optimal content level—specifically 2% nanosilica—beyond which further addition becomes counterproductive. The mechanical strengths (compressive, tensile, and flexural) as well as durability (water absorption resistance) are maximized at this level.In conclusion, the incorporation of nanosilica in geopolymer concrete significantly improves its performance, especially when used in optimal proportion. Among the tested samples, 2% nanosilica was found to deliver the best overall results. This finding highlights the potential of nanosilica as a key additive in the development of high-performance, durable, and sustainable geopolymer concrete for modern construction applications.

REFERENCES

1. Zhong Xu, Hongyuan Long, Qingfeng Liu, Haolong Yu, Xiaoli Zhang, David Hui. mechanical Properties and durability of geopolymer concrete based on fly ash and coal gangue under different dosage and particle size of nano silica, Construction and Building Materials Volume 387, 17 July 2023, 131622
2. Cut Rahmawati, Sri Aprilia, Taufiq Saidi, Teuku Budi Aulia, Agung Efriyo Hadi. The Effects of Nanosilica on Mechanical Properties and Fracture Toughness of Geopolymer Cement. *Polymers* 2021, *13*(13), 2178; https://doi.org/10.3390/polym13132178
3. Mohammed Abd El-Salam Arab, Ayman Sayed Mohamed, Mahmoud Kamal Taha, Ahmed nasr, Microstructure, durability and mechanical properties of high strength geopolymer concrete containing calcinated nano-silica fume/nano-alumina blend. Construction and Building Materials, Volume 472, 18 April 2025, 140903.
4. Yali Hu, Zhangli Wang, Shuai Zong, Daopei Zhu, The effect of nano-SiO_2 on the mechanical properties and degradation of steel fiber-reinforced geopolymer composite material under freeze-thaw cycles. Construction and Building Materials , Volume 475, 16 May 2025, 141198.
5. 5.Reddy, A. N., Priyanka, S. P., & Mounika, P. (2019). The effect of nano silica on mechanical properties of concrete. Int. Res. J. Appl. Sci, 1(1), 36-40.
6. Mohammadhossein mansourghanaei, Morteza Biklaryan, Alireza Mardookhpour, Experimental study of the effects of adding silica nanoparticles on the durability of geopolymer concrete. https://doi.org/10.1080/14488353.2022.2120247.
7. Mohammadhossein mansourghanaei, Morteza Biklaryan, Alireza Mardookhpour, Durability and Mechanical 7. Properties of Granulated Blast Furnace Slag Based Geopolymer Concrete Containing

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International Journal of Engineering Technology Research & Management
Published By:
https://www.ijetrm.com/

Polyolefin Fibers and Nano Silica. KSCE Journal of Civil Engineering, Volume 28, Issue 1, January 2024, Pages 209-219.

8. Bheem Pratap, Analysis of the synergistic effects of micro silica on the mechanical and durability properties of geopolymer concrete incorporating phosphogypsum, Journal of Building Engineering, Volume 93, 15 September 2024, 109831.
9. Liu Yang , Zhiduo Zhu , Dingwen Zhang , He Sun ,Wangwen Huo, Jie Zhang ,Yu Wan ,Chen Zhang , Influence mechanism of Nano-SiO_2 on geopolymer recycled concrete: Change mechanism of the microstructure and the anti-carbonation mechanism, Cement and Concrete Composites, Volume 146, February 2024, 105364.
10. Gill, Parveen Jangra, Rajeev Roychand, Mohammad Saberian, Jie Li, Effects of various additives on the crumb rubber integrated geopolymer concrete, Cleaner Materials volume 8, June 2023, 100181
11. Reddy, A. N., & Meena, T. (2017). A comprehensive overview on Performance of Alccofine concrete. International Journal of Pharmacy & Technology, 9(1).
12. Priyanka Kamtekar, Komal Bane, Archana Kharpade, Sujit Chothe, Geopolymer Bricks VIVA- Tech International Journal for Research and Innovation, ISSN(Online): 2581-7280 Volume 1, Issue 4 (2022)
13. Kumutha Rathinam, Karthick Kumar P. V., Srikiruthiga S., Vijay P, interlocking bricks and prisms using waste glass aggregates by integrating geopolymer technology, Journal Teknologi 86:4 (2024) 51–58.
14. S.S.Vivek, B. Alamelu Mangai, Study on interlocking geo-polymer interlocking earth blocks made with residual rice husk ash and fly ash, Materials today: proceedings (2023)
15. Reddy, A. N., & Meena, T. (2021). Acid resistance of ternary blended nanosilica concrete incorporating fly ash and alccofine. pores, 26, 27.
16. Gaurav Udgata, Kirtikanta Sahoo, Dipti Ranjan Biswal, Subham Sahoo, Sustainable Investigation on Pond Ash Induced Compressed Interlocking Bricks, ISSN (Online) 2454 - 7190 Vol.-19, No.-6, June (2024) pp 25-36
17. Reddy, A. N., Reddy, P. N., Kavyateja, B. V., & Reddy, G. G. K. (2020). Influence of nanomaterial on high-volume fly ash concrete: a statistical approach. Innov Infrastruct Solut 5: 88.
18. Hongxiang Gou, Madhuwanthi Rupasingahe, Massoud Sofi, Rajesh Sharma, Gianluca Ranzi, Priyan Mendis, Zipeng Zhang, A Review On Cementitious And Geopolymer Composites With Lithium Slag Incorporation, Materials 2024, 17(1), 14
19. Reddy, A. N., Rajesh, D. V. S. P., Reddy, T. R. P., Tilak, U. V., & Rani, N. S. An Experimental Investigation Influence of Fibers on Concrete Under Elevated Temperature.
20. Yongqian Zheng, Biao He, Yanjun Xiao, Strength and microstructure of geopolymer recycled brick aggregate concrete after high temperatures, Construction and Building Materials, Volume 448, 18 October 2024, 138263