World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(Research Article)

Check for updates

Use of waste clay brick powder as a partial replacement binder in geo-polymer concrete

Pallavi Prasanth Kartha *

Department of Civil Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, Tamil Nadu, India.

World Journal of Advanced Engineering Technology and Sciences, 2024, 13(02), 472–481

Publication history: Received on 19 October 2024; revised on 07 December 2024; accepted on 09 December 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.13.2.0594

Abstract

Geopolymer concrete is gaining as a sustainable alternative to traditional concrete due to its lower carbon footprint and use of industrial by-products. This study thoroughly examines the effectiveness of incorporating waste clay brick as a partial replacement binder in geopolymer concrete, specifically aiming to reduce environmental impact and improve mechanical and durability properties. Various geopolymer concrete formulations were methodically developed, with the inclusion of waste clay brick as a supplementary binder material at different replacement levels. Compressive strength, flexural strength, and split tensile strength exhibit promising results, with certain mix proportions showing enhanced performance compared to the control mix. Based on waste clay brick samples tested, the compressive strengths for both 20% and 30% binder samples remained between 25 MPa and 27 MPa. The flexural strength and the split tensile strength of the binder specimens showed nearly maximum higher strength. The reduction in water absorption also signifies enhanced long-term durability which was found to have 2 – 3%. Compared to GPC, the binder proportions investigated here showed much higher strength. Using 30% of the waste clay brick as a partial replacement binder in geopolymer concrete presents a promising avenue for sustainable construction practices.

Keywords: Geopolymer concrete; Waste clay brick powder; Partial replacement binder; Durability; Sustainable alternative.

1. Introduction

The building sector has faced more pressure in recent years to address environmental issues and lessen its carbon footprint. Due to its high carbon dioxide emissions during production, traditional Portland cement, a vital component of concrete, is notorious for having a substantial negative environmental impact. Because of this, scientists and industry professionals are working hard to investigate substitute materials and technologies that can lessen the negative effects on the environment while preserving or even enhancing the capabilities of building materials. In this sense, geopolymer concrete has shown promise as a sustainable substitute for concrete made mostly of Portland cement.

Geopolymer concrete is produced by activating aluminosilicate materials with alkaline solutions, resulting in a binder that chemically resembles traditional cementitious binders but with significantly lower carbon emissions. The primary raw materials used in geopolymer concrete typically include industrial by-products such as fly ash, GGBFS, and metakaolin. However, the utilization of waste materials as alternative binders in geopolymer concrete presents an opportunity to further enhance sustainability and resource efficiency in the construction industry.

One such waste material with potential as a partial replacement binder in geopolymer concrete is waste clay brick. Clay brick waste is generated from construction and demolition activities, representing a significant environmental burden

---

[*] Corresponding author: Pallavi Prasanth Kartha.

if not properly managed. However, by incorporating waste clay brick into geopolymer concrete, not only can the environmental impact of clay brick waste disposal be mitigated, but also the performance of geopolymer concrete may be enhanced through the utilization of additional reactive materials.

This study aims to investigate the feasibility of utilizing waste clay brick as a partial replacement binder in geopolymer concrete. Firstly, it offers a sustainable solution by recycling construction waste, reducing landfill burden, and conserving natural resources. Secondly, it enhances the environmental benefits of geopolymer concrete, which already has a lower carbon footprint than traditional Portland cement. The process further decreases CO_2 emissions associated with cement production by incorporating waste clay brick. Lastly, this approach can improve the economic viability of geopolymer concrete by utilizing locally available waste materials, potentially lowering material costs and promoting circular economy principles in the construction industry.

2. Materials and methodology

2.1. Materials

The detailed breakdown of the materials required for incorporating waste clay brick into geopolymer concrete are as follows:

2.1.1. Waste Clay Brick (WCB)

The primary material is waste clay brick. Waste clay bricks, which are often discarded from demolished buildings or construction sites, can be repurposed as a valuable raw material in geopolymer concrete production. Mainly, waste clay bricks are collected and then hand-crushed. With the help of a Pulveriser Machine, the bricks are again crushed into fine powder and then sieved. (Table 2). It is sieved with the 90-micron sieve and then arranged according to their composition of their content as 10%, 20%, 30%, 40% respectively (Table 1).

2.1.2. Geopolymer Concrete

Geopolymer concrete as an aluminosilicate source is prepared. It relies on aluminosilicate materials as the primary source for the reactive components that form the geopolymer binder. Common aluminosilicate sources include:

- *Fly Ash*

Fly ash is a widely used material in the production of geopolymer concrete due to its abundance as a by-product of coal combustion in thermal power plants. It is primarily composed of fine, spherical particles that are rich in Silica (SiO2) and Alumina (Al2O3). Mainly, class of F-grade of fly ash is used in this project (Table 1, 2).

- *Ground Granulated Blast Furnace Slag (GGBFS)*

Ground Granulated Blast Furnace Slag (GGBFS) is another common material used in the production of geopolymer concrete (Table 1, 2). Like fly ash, GGBFS contains reactive components such as silica and alumina, which can undergo polymerization when activated with alkaline solutions to form the geopolymer binder.

2.1.3. Alkaline Activators

Alkaline activators are crucial for initiating the geopolymerization reaction (Table 1). They typically consist of:

- *Sodium Hydroxide (NAOH)*

Sodium Hydroxide is a strong alkaline compound that plays a primary role in activating the geopolymerization reaction (Table 3). The flakes of required amount are mixed with water kept for 24hrs.

- *Sodium Silicate (Na_2SiO_3)*

Sodium silicate, commonly known as waterglass, is a solution of sodium oxide (Na_2O) and silica (SiO_2) in water (Table 3).

2.1.4. Aggregates

Aggregates are used to impart bulk and strength to the concrete mixture (Table 1). They include:

- *Fine Aggregates*

Fine aggregates, typically consist of particles smaller than 5mm in diameter (Table 2). They are used to fill the voids between coarse aggregate particles and bind the geopolymer binder together.

- *Coarse Aggregates*

Coarse aggregates consist of particles larger than 5mm in diameter (Table 3). Coarse aggregates are typically categorized based on their nominal size, with common sizes including 10mm and 20mm aggregates. Here, aggregates passing 10mm and 20mm are taken respectively.

2.1.5. Water

Water is necessary for activating the geopolymerization process and achieving the desired workability of the concrete mix (Table 1, 3).

2.2. Mix Proportion

2.2.1. Mix Ratio

Table 1 Mix Ratio Values of each material

Material	Fly Ash	GGBFS	Waste Brick Powder (%)	Fine Aggregate	Coarse Aggregate		Na2SiO3	NaOH	Extra Water
	(%)	(%)			20mm	10mm			
Quantity (in kg/m^3)	70	30	0	832	610	406	102.22	40.89	41
	60	30	10	832	610	406	102.22	40.89	41
	50	30	20	832	610	406	102.22	40.89	41
	40	30	30	832	610	406	102.22	40.89	41
	30	30	40	832	610	406	102.22	40.89	41

2.2.2. Base Calculation

Table 2 Quantity of Materials Required

SL NO.	Material	Fly Ash	GGBFS	Waste Brick Powder (WBP)	Fine Aggregate	Specimen
SET 1	Quantity (in kg)	9.597	4.1106	0	27.9075	Actual Geopolymer Specimen
SET 2		8.222	4.1106	1.3683	27.9075	Binder Specimens
SET 3		6.8523	4.1106	3.7403	27.9075	
SET 4		5.5729	4.1106	4.1103	27.9075	
SET 5		4.9073	4.1106	5.4829	27.9075	

Table 3 Quantity of Materials Required

SL NO.	Coarse Aggregate		Na2SiO3	NaOH	Extra Water	Specimen	Total Quantity Required FOR EACH SET (in kg)
	20mm	10mm					
SET 1	20.46	13.613	7.13435	2.852625	1.3742	Actual Geopolymer Specimen	87.049275
SET 2	20.46	13.613	7.13435	2.852625	1.3742	Binder Specimens	87.042575
SET 3	20.46	13.613	7.13435	2.852625	1.3742		88.044875
SET 4	20.46	13.613	7.13435	2.852625	1.3742		87.135475
SET 5	20.46	13.613	7.13435	2.852625	1.3742		87.842475

2.3. Methodology

2.3.1. Compressive Strength Test (IS:516-2021)

A 100 x 100 x 100 mm cube specimen was utilized to measure the strength under compression. Subsequently, the specimen sample was positioned so as to apply the load perpendicular to the casting's side. We applied the weight at a consistent rate. The failure load was recorded, and the specimen will automatically be unloaded. The concrete's compressive strength was calculated using the formula below.

Compressive Strength = Load / Cross-sectional Area

2.3.2. Flexural Strength Test (IS:516-2021)

The flexural strength of the concrete was tested using a beam specimen of 100 x 100 x 500 mm. A Flexural testing machine was used to conduct a three-point test in accordance with IS 516 (2021).

MR (modulus of rupture) = $3PL / 2bd^2$

2.3.3. Split Tensile Strength Test (IS:516-2021)

For the split tensile test, a specimen with a diameter of 150 mm and a height of 300 mm was utilized. In the compression testing apparatus, the load was applied steadily. The failure load was recorded, and the specimen will automatically be unloaded. The following formula was used to determine the concrete's tensile strength.

Fct (Tensile strength of concrete) = $2P / \pi DL$

2.3.4. Water Absorption Test (ASTM C 1585)

The water absorption test of concrete involves the measure of amount of water it absorbs over a specified period. First, concrete specimens are weighed (w1) and subsequently immersed in water for 24 hours. After the immersion period, the specimens are removed, surface-dried with a cloth, and weighed again (w2). The difference in weight before and after immersion, expressed as a percentage of the dry weight, represents the water absorption of the concrete.

Water Absorption (%) = $(w1 - w2) / w1 \times 100$

2.3.5. Sorptivity Test (ASTM C1585-20)

To perform the test, a concrete specimen is partially immersed in water to a depth of 5-10 mm, with the sides sealed to ensure one-dimensional water flow. The mass of the specimen is recorded at specific time intervals (0, 15, 60, 240, and 1440 minutes) as it absorbs water. The sorptivity coefficient is determined by plotting the absorbed water against the square root of time.

$$\mathbf{I = \frac{M_t - M_0}{A \times \rho}}$$

$$\mathbf{S} = \frac{\mathbf{I}}{\sqrt{\mathbf{t}}}$$

Where, I = Cumulative Water Absorption (%)

- S = Sorptivity (%)
- Mt = Mass of the specimen(g) at Time t (min)
- M0 = Initial dry mass (g)
- A = Cross-sectional area (mm2)
- ρ = Density of water. (1000 kg/m3)

2.3.6. Elevated Temperature Test (ASTM E119)

The specimens are placed in a furnace where the temperature is gradually increased to the target level (600°C, 800°C) and maintained for a specified duration, typically 3 hours. Once cooled, the specimens are tested for changes in mechanical properties such as compressive strength, to assess the impact of the high-temperature exposure.

Weight Loss (%) = (w1 – w2) / w1 × 100

Compressive Strength = Load / Cross-sectional Area

3. Results and discussion

3.1. Compressive Strength

The following trend shows the compressive strength of the control mix and binder specimens:

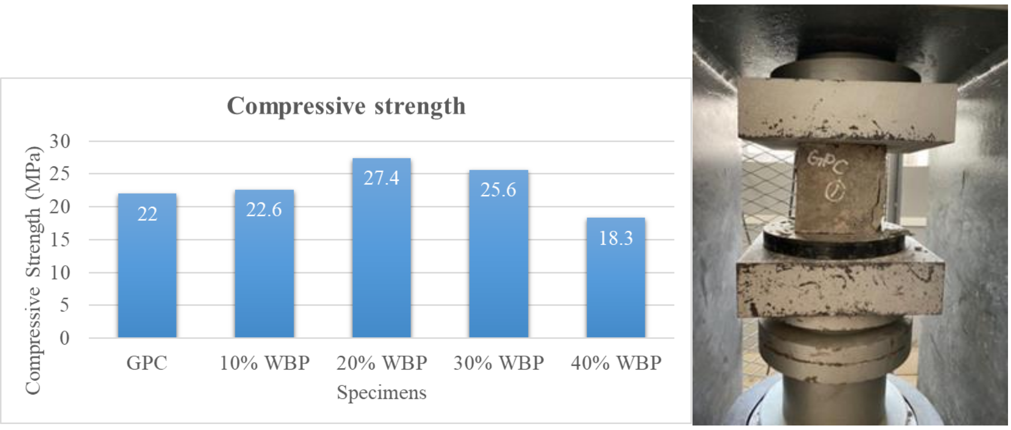

Figure 1 Compressive Strength of the Specimens for 28 days

Three samples of prepared geopolymer concrete, 10%, 20%, 30%, and 40% binder samples were cast and kept under curing for 28 days and compressive tests were done. The average from three sets of cubes was taken and the results show that the mix with the highest strength, or maximum compression strength was observed in 20% and 30% of waste brick binder samples.

This shows that 20% and 30% of waste clay brick binder samples has achieved higher strength and can be further eligible for construction purposes.

3.2. Flexural Strength

The following trend shows the flexural strength of the control mix and binder specimens:

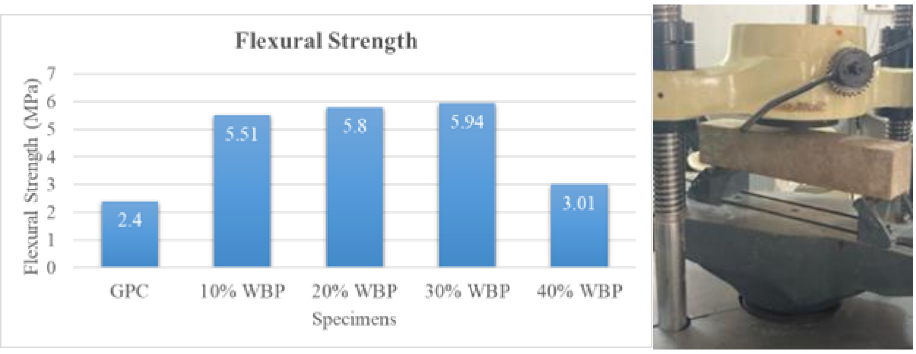

Figure 2 Flexural Strength of the Specimens for 28 days

Two samples each of prepared geopolymer concrete, 10%, 20%, 30%, and 40% binder samples were cast and kept under curing for 28 days, and flexural tests were done. The average from two sets of beams was taken and the results show that the mix with the highest strength, or maximum flexural strength was observed in both 20% and 30% of waste brick binder samples.

This shows that both 20% and 30% of waste clay brick binder samples have achieved higher strength and can be further eligible for construction purposes.

3.3. Split Tensile Strength

The following trend shows the split tensile strength of the control mix and binder specimens:

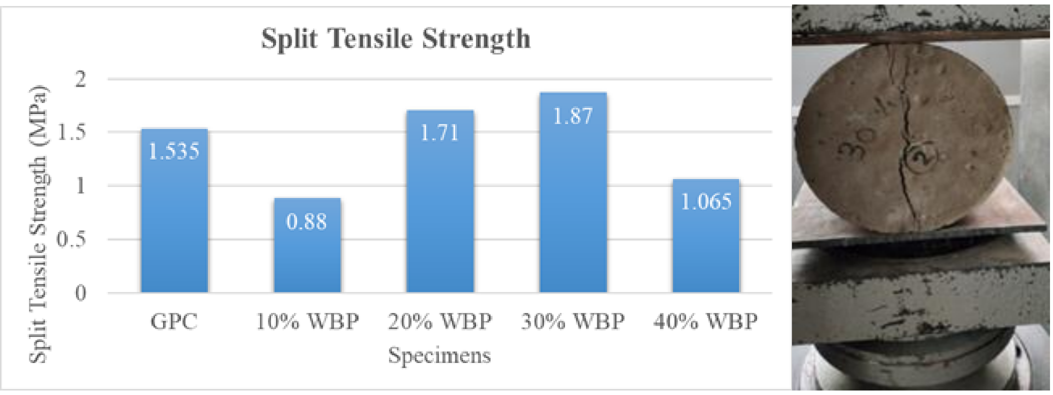

Figure 3 Split Tensile Strength of the Specimens for 28 days

Two samples of prepared geopolymer concrete, 10%, 20%, 30%, and 40% binder samples were cast and kept under curing for 28 days and split tensile tests were done. The average from two sets of cylinders was taken and the results show that the mix with the highest strength, or maximum split tensile strength was observed in 30% of the waste brick binder sample.

This shows that 30% of waste clay brick binder samples have achieved higher strength and can be further eligible for construction purposes.

3.4. Water Absorption

The following trend shows the water absorption test of the control mix and binder specimens:

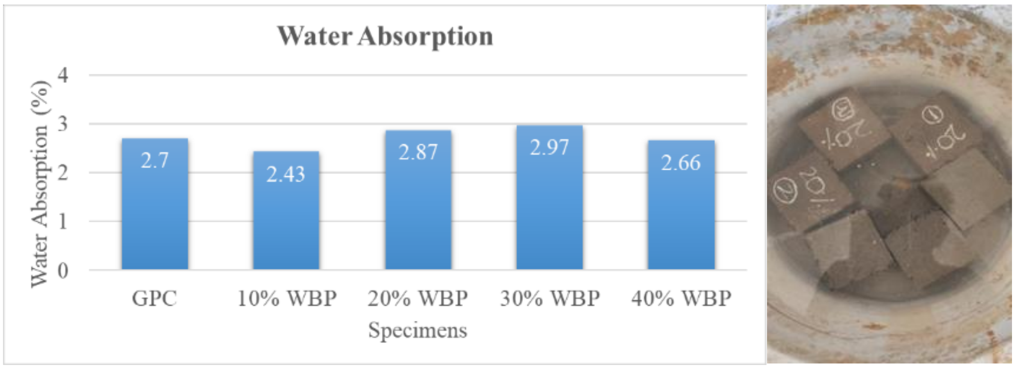

Figure 4 Water Absorption Test Results

The water absorption was conducted and the results show that 30% of waste clay brick binder samples are found to have lower water absorption. The value obtained is within the range (2% - 3%).

3.5. Sorptivity

The following trend shows the cumulative water absorption rate of the control mix and binder specimens:

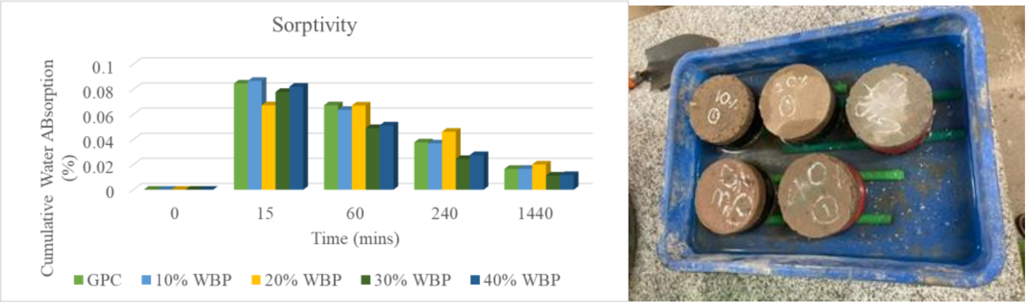

Figure 5 Sorptivity Test Results

The sorptivity test was conducted, and the results show that 30% of waste clay brick binder samples have lower sorptivity, resulting in high durability and low permeability. The value obtained is < 0.02mm/min$^{0.5}$.

3.6. Elevated Temperature

The following trend shows the compressive strength of the control mix and binder specimens after keeping at the respective temperatures:

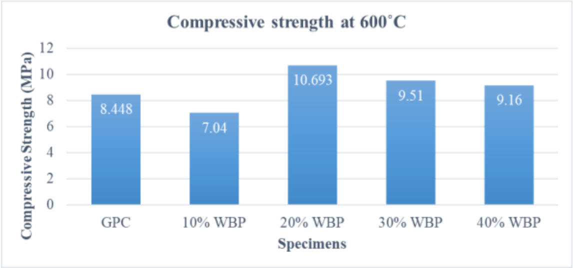	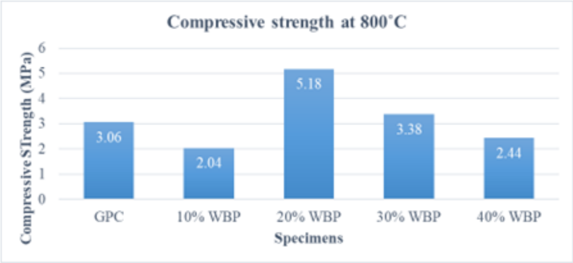
Figure 6a. (Elevated Temperature Test at 600˚C)	**Figure 6b (**Elevated Temperature Test at 800˚C

	Fig. 6.c (Specimen after heating)

The elevated temperature test was conducted at both 600˚C and 800˚C. The results show that 30% of waste clay brick binder samples are found to have higher weight loss. According to the compressive strength results, 20% and 30% of waste clay brick binder samples achieved lower strength after heating both temperatures. This resulted in severe strength loss where the value was often falling below 10MPa. The colour change to light reddish was observed.

4. Conclusion

Using waste clay brick as a partial replacement binder in geopolymer concrete presents a promising avenue for sustainable construction practices. Based on experimentation and analysis, the results are obtained and the following conclusions are made:

- From the test results, it is found that 20% and 30% of the WCB binder samples achieve higher compressive strength when compared to the control mix.
- In the case of both flexural strength and split tensile strength, 30% of the WCB binder samples are found to have maximum strength.
- In the case of the water absorption test, all the specimens had a lower absorption rate than the control mix, which is below 3%.
- Lower sorptivity is found in 30% of the WCB binder sample with a value < $0.02 mm/min^{0.5}$.
- The elevated temperature test was conducted at both 600˚C and 800˚C and was found to have a higher weight loss percentage with severe strength loss for both 20% and 30% WCB binder samples.
- Apart from water absorption and elevated temperature test, and comparing to other test results, 30% of the WCB binder sample is found to have maximum strength and may be found to be eligible for construction purposes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Uysal, M., Aygörmez, Y., Canpolat, O., Cosgun, T., & Faruk Kuranlı, Ö. (2022). Investigation of using waste marble powder, brick powder, ceramic powder, glass powder, and rice husk ash as eco-friendly aggregate in sustainable red mud-metakaolin-based geopolymer composites. Construction and Building Materials, 361(November). https://doi.org/10.1016/j.conbuildmat.2022.129718

[2] Likes, L., Markandeya, A., Haider, M. M., Bollinger, D., McCloy, J. S., & Nassiri, S. (2022). Recycled concrete and brick powders as supplements to Portland cement for more sustainable concrete. Journal of Cleaner Production, 364(March). https://doi.org/10.1016/j.jclepro.2022.132651

[3] He, Z., Shen, A., Wu, H., Wang, W., Wang, L., Yao, C., & Wu, J. (2021). Research progress on recycled clay brick waste as an alternative to cement for sustainable construction materials. Construction and Building Materials, 274, 122113. https://doi.org/10.1016/j.conbuildmat.2020.122113

[4] Migunthanna, J., Rajeev, P., & Sanjayan, J. (2023). Waste Clay Brick as a Part Binder for Pavement Grade Geopolymer Concrete. International Journal of Pavement Research and Technology, 0123456789. https://doi.org/10.1007/s42947-023-00312-z

[5] Fořt, J., Novotný, R., Vejmelková, E., Trník, A., Rovnaníková, P., Keppert, M., Pommer, V., & Černý, R. (2019). Characterization of geopolymers prepared using powdered brick. Journal of Materials Research and Technology, 8(6), 6253–6261. https://doi.org/10.1016/j.jmrt.2019.10.019

[6] Tuyan, M., Andiç-Çakir, Ö., & Ramyar, K. (2018). Effect of alkali activator concentration and curing condition on strength and microstructure of waste clay brick powder-based geopolymer. Composites Part B: Engineering, 135(October 2017), 242–252. https://doi.org/10.1016/j.compositesb.2017.10.013

[7] Reig, L., Tashima, M. M., Borrachero, M. V., Monzó, J., Cheeseman, C. R., & Payá, J. (2013). Properties and microstructure of alkali-activated red clay brick waste. Construction and Building Materials, 43, 98–106. https://doi.org/10.1016/j.conbuildmat.2013.01.031

[8] Zawrah, M. F., Gado, R. A., Feltin, N., Ducourtieux, S., & Devoille, L. (2016). Recycling and utilization assessment of waste-fired clay bricks (Grog) with granulated blast-furnace slag for geopolymer production. Process Safety and Environmental Protection, 103, 237–251. https://doi.org/10.1016/j.psep.2016.08.001

[9] Janardhan, P., Krishnaiah, R. V., & Raju, K. V. B. (2024). Materials Today : Proceedings Experimental study on the performance of strength and sorptivity of fiber-reinforced alkali-activated geopolymer concrete. Materials Today: Proceedings, March, 5–10. https://doi.org/10.1016/j.matpr.2024.05.064

[10] Ruan, S., Yan, D., Chen, S., Jiang, F., & Shi, W. (2022). Process and mechanisms of multi-stage water sorptivity in hydrophobic geopolymers incorporating polydimethylsiloxane. Cement and Concrete Composites, 128(February), 104460. https://doi.org/10.1016/j.cemconcomp.2022.104460

[11] Wang, T., Yu, M., Lin, H., Li, D., & Li, L. (2024). Experimental investigation of mechanical properties of GGBS-FA-SF blended geopolymer concrete at elevated temperatures. Fire Safety Journal, 146(February), 104156. https://doi.org/10.1016/j.firesaf.2024.104156

[12] Arjun Raj, P. K., Sarath, D., Nagarajan, P., & Shashikala, A. P. (2023). The behavior of geopolymer concrete at elevated temperature- a comprehensive review. Materials Today: Proceedings, xxxx. https://doi.org/10.1016/j.matpr.2023.03.521

[13] Özbayrak, A., Kucukgoncu, H., Aslanbay, H. H., Aslanbay, Y. G., & Atas, O. (2023). Comprehensive experimental analysis of the effects of elevated temperatures in geopolymer concretes with variable alkali activator ratios. Journal of Building Engineering, 68(February). https://doi.org/10.1016/j.jobe.2023.106108

[14] Bureau of Indian Standards. (2021). IS 516 : 2021 - Hardened concrete - Methods of test. *Bureau of Indian Standards*, *516*(March), 1–20. www.standardsbis.in

[15] ASTM-Internacional. (1992). ASTM E119 - Standard test methods for fire test of building construction and materials. *American Society for Testing and Materials - ASTM*, *552*(1), 36. www.aslm.org

[16] Hasan, K., Yahaya, F. M., Karim, A., & Othman, R. (2021). Investigation on the Properties of Mortar Containing Palm Oil Fuel Ash and Seashell Powder as Partial Cement Replacement. *Construction*, *1*(2), 50–61. https://doi.org/10.15282/construction.v1i2.6679

[17] Sunarsih, E. S., As'ad, S., Sam, A. R. M., & Kristiawan, S. A. (2023). Properties of Fly Ash-Slag-Based Geopolymer Concrete with Low Molarity Sodium Hydroxide. *Civil Engineering Journal (Iran)*, *9*(2), 381–392. https://doi.org/10.28991/CEJ-2023-09-02-010

[18] Faheem, M. T. M., Al Bakri, A. M. M., Kamarudin, H., Binhussain, M., Ruzaidi, C. M., & Izzat, A. M. (2013). Application of clay - based geopolymer in brick production: A review. *Advanced Materials Research*, *626*(March 2014), 878–882. https://doi.org/10.4028/www.scientific.net/AMR.626.878

[19] Aygörmez, Y. (2021). Performance of ambient and freezing-thawing cured metazeolite and slag based geopolymer composites against elevated temperatures. *Revista de La Construccion*, *20*(1), 145–162. https://doi.org/10.7764/RDLC.20.1.145

[20] Seifan, M., Mendoza, S., & Berenjian, A. (2020). Mechanical properties and durability performance of fly ash based mortar containing nano- and micro-silica additives. *Construction and Building Materials*, *252*(2020). https://doi.org/10.1016/j.conbuildmat.2020.119121

[21] Sukmak, P., Horpibulsuk, S., & Shen, S. L. (2013). Strength development in clay-fly ash geopolymer. *Construction and Building Materials*, *40*, 566–574 https://doi.org/10.1016/j.conbuildmat.2012.11.015

[22] Takekar, A., & Patil, G. R. (2017). Experimental Study on Mechanical Properties of Fly Ash and Ggbs Based Geopolymer Concrete. *International Research Journal of Engineering and Technology*. www.irjet.net

[23] Ahmed, H. Q., Jaf, D. K., & Yaseen, S. A. (2020). Flexural strength and failure of geopolymer concrete beams reinforced with carbon fibre-reinforced polymer bars. *Construction and Building Materials*, *231*, 117185. https://doi.org/10.1016/j.conbuildmat.2019.117185

[24] Ahmed, H. Q., Jaf, D. K., & Yaseen, S. A. (2020). Flexural strength and failure of geopolymer concrete beams reinforced with carbon fibre-reinforced polymer bars. *Construction and Building Materials*, *231*, 117185. https://doi.org/10.1016/j.conbuildmat.2019.117185

[25] He, Z., Shen, A., Wu, H., Wang, W., Wang, L., Yao, C., & Wu, J. (2021). Research progress on recycled clay brick waste as an alternative to cement for sustainable construction materials. *Construction and Building Materials*, *274*, 122113. https://doi.org/10.1016/j.conbuildmat.2020.122113

[26] Mizoue, Y., Sencer, B., & Beaucamp, A. (2020). Jo ur na l P re of. *International Journal of Machine Tools and Manufacture*, 103648. https://doi.org/10.1016/j.ijmachtools.2020.103648

[27] Balakrishna, M. ., Evans, R., Mohammad, F., & Rahman, M. . (2020). Water Absorption Capacity of Concrete Cubes with Sorptivity Water. *International Research Journal of Engineering and Technology (IRJET)*, *7*(4), 721–727.

[28] Moore, A., Bakera, A. T., & Alexander, M. (2020). *Water Sorptivity and Porosity Testing of Concrete Durability of concrete structures View project CoMSIRU at UCT View project*. *September*. https://doi.org/10.13140/RG.2.2.21185.07525