International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

REVIEW ON ENHANCE THE MECHANICAL PROPERTIES OF ACTIVATING SOLUTION CONCRETE

VARUN KUMAR[a], SAPANA MADAN[b]

[a]M.Tech. Scholar, School of Civil Engineering, Faculty of Engineering and Technology Madhyanchal Professional University Bhopal, M.P
[b]Associate Professor, School of Civil Engineering, Faculty of Engineering and Technology Madhyanchal Professional University Bhopal, M.P

ABSTRACT :

The improved compressive, flexural, and split tensile strengths of GPC with higher molarity of alkaline activators (commonly sodium hydroxide and sodium silicate) demonstrate its potential for structural applications. The chemical reaction between aluminosilicate materials and alkaline solutions forms a strong geopolymer matrix, offering enhanced durability and resistance to aggressive environments, such as sulfate attack and chloride penetration. Incorporating iron slag powder improves mechanical performance and enhances durability. Geopolymer concrete (GPC) represents an innovative and environmentally friendly alternative to Ordinary Portland Cement (OPC) concrete. Unlike traditional concrete, GPC does not rely on OPC, thereby significantly reducing carbon dioxide emissions—a major contributor to climate change.

Keywords: Higher molarity, Fly ash, geopolymer matrix iron slag powder, environmentally friendly

Introduction :

Iron Powder Slag with Geo Polymer Concrete. Iron powder slag, a by-product of steel manufacturing, can be effectively utilized as a partial or complete replacement material in geo polymer concrete (GPC) to enhance its properties. This approach promotes sustainability and reduces industrial waste by recycling slag material. Incorporating *iron powder slag* with *geo-polymer concrete (GPC)* can bring significant benefits to both sustainability and material performance. Here's a detailed look into this concept. Replacing *fly ash* with *iron slag* in *geopolymer concrete (GPC)* is a viable approach to improve sustainability and performance. Iron slag, particularly *ground granulated blast furnace slag (GGBFS)***,** can act as a *primary alumina-silicate source* or a *partial replacement* in geopolymer binders. Replacing *fly ash* with *iron slag* in geopolymer concrete improves *strength, durability, and sustainability*. However, it also requires careful consideration of *mix design***,** *curing conditions***,** and *workability management***.** It is ideal for applications demanding *high-performance concrete* with *early strength requirements*.

Xin Cai et al (2024) this summary provides a detailed review of the impact of iron slag (SS) on cement-based materials, specifically focusing on its effects on mechanical properties and durability. Iron slag increases the fluidity of cement-based materials, which is important for ease of handling and mixing. However, it also significantly lengthens the setting time of the mixture, extending it by 210% to 300% compared to traditional Portland cement (PC). When iron slag is used as a replacement, the compressive strength of concrete can reach 60–80 MPa when the replacement rate is 50%. This is indicative of its potential to enhance the material's strength. The bending (or flexural) strength of concrete incorporating iron slag can reach 6–9 MPa, which is a notable improvement, suggesting enhanced resistance to bending forces. Concrete made with an optimal amount of iron slag (replacement rate of about 50%) shows a 15–20% improvement in frost resistance, making it more suitable for cold climates where freeze-thaw cycles can cause damage. Iron slag enhances the resistance of concrete to sulfate attacks, which can otherwise lead to deterioration in aggressive environments. Iron slag concrete exhibits reduced permeability, with a decrease of up to 30%. This reduction in permeability is crucial for improving the concrete's durability by preventing the ingress of water and harmful substances. The management of iron slag is critical, as improper disposal can lead to environmental issues. By incorporating iron slag into concrete, its potential environmental impact is mitigated by reducing waste and enhancing the performance of construction materials. In conclusion, using iron slag as a replacement in cement-based materials can significantly improve their mechanical and durability properties, making it a promising alternative to conventional Portland cement, provided proper management practices are in place to mitigate any environmental risks associated with iron slag disposal.

Shaofeng Zhang et al (2023) this study aims to improve the mechanical properties of cement-iron slag mortar by the addition of alkaline activators (NaOH, Na_2CO_3/NaOH and water glass) to promote the optimal utilization of iron slag. In this paper, the setting time, flexural and compressive strength, early-age hydration kinetics and microstructure are investigated to explore how the alkaline activators influence the hydration of cement-iron slag system. The results indicate that the incorporation alkaline activators shortens the setting time and enhances the mechanical strength of cement-iron slag composite binder, which are ranked from large to small in the order of water glass >Na_2CO_3/NaOH > NaOH. Moreover, the hydration exothermic action of cement-iron slag activated by alkaline activators is significantly accelerated in comparison to cement-iron slag. Furthermore, the incorporation of alkaline activators promotes the formation of amorphous gel products, such as gel, of cement-iron slag system, which can fill the capillary pores and convert them into gel pores with a smaller pore size, leading to a denser microstructure. Based on the outcome of different analytical techniques, it is observed that alkaline activators can facilitate disintegration of iron slag's vitreous structure and can be applied to enhance the reactivity of iron slag in the cement-iron slag system to develop a sustainable composite cement.

Zhengyi Ren et al (2023) Iron slag is a solid waste produced in crude iron smelting, and a typical management option is stockpiling in slag disposal yards. Over the years, the massive production of iron slags and the continuous use of residue yards have led to vast occupation of land resources and caused severe environmental concerns. Iron slag particles can potentially be used as aggregates in concrete production. However, the volume stability of iron slag is poor, and the direct use of untreated iron slag aggregate (SSA) may cause cracking and spalling of concrete. The present research summarizes, analyzes, and compares the chemical, physical, and mechanical properties of iron slags. The mechanism and treatment methods of volume expansion are introduced, and the advantages, disadvantages, and applicable targets of these methods are discussed. Then, the latest research progress of iron slag aggregate concrete (SSAC) is reviewed. Using SSA leads to an increase in the density of concrete and a decrease in workability, but the mechanical properties and durability of SSAC are superior to natural aggregate concrete (NAC). Finally, future research in this field is proposed to motivate further studies and guide decision-making.

Mr.T.Vijayashankar et al (2023) study on using steel slag as coarse aggregate in geopolymer concrete (GPC) provides valuable insights into sustainable construction materials. Highlighting the replacement of natural coarse aggregates with steel slag in a cement-free geopolymer matrix adds significance to addressing environmental concerns and promoting circular economy practices.

The results indicate that the mechanical performance of GPC with steel slag, including compressive, tensile, flexural strengths, and durability tests like rebound hammer and ultrasonic pulse velocity, is comparable to conventional aggregates. This supports the feasibility of using industrial by-products in sustainable concrete applications.

Mix Proportions and Optimization – Details of alkaline activators, molarity, and curing conditions to ensure reproducibility.

Microstructural Analysis – Using SEM or XRD to confirm bond strength and matrix densification between geopolymer gel and steel slag.

Durability Aspects – Long-term performance under aggressive environments, chloride ingress, and sulfate attack resistance.

Such additions can make your findings more robust and demonstrate the practical viability of GPC with steel slag in real-world applications.

Rahul D. Pawar et al (2022) the main objective is to produce lightweight geopolymer concrete using expanded polystyrene (EPS) beads as partial replacement of the fine aggregates for building components. The selection of EPS bead aggregate was made mainly due to its low density, closed cellular structure, hydrophobic and energy absorbing characteristics. Also, to study the strength characteristics of light weight geopolymer concrete using different combinations. Previously, several studies were conducted on mix details, strength properties, drying shrinkage, compaction and finishing etc. of the geopolymer concretes .A new material that has been introduced in the construction field called Geopolymer concrete in which cement is totally replaced by Fly ash rich in Aluminum (Al) and Silicon (Si). When the polymerization process of highly alkaline liquids is activated, the materials start to bind with aggregates in concrete. Expanded Polystyrene (EPS) is a lightweight material that is used in various Engineering, industrial, commercial as well as household applications. It has density that is about a couple of hundredth of that of soil. It has compressive strength comparable to medium clay and has good thermal insulation properties with stiffness. It is mainly use to reduce settlement below embankments, reducing lateral pressure on sub-structures, reducing stresses on rigid buried conduits and related applications, sound and vibration damping. EPS is very light in weight and has grainy form which is used as aggregate to create a light weight structural concrete. It has unit weight varying from 1200 to 2000 kg per m^3. As polystyrene aggregate is light weight and high density, concrete can be created by partially replacing sand (fine aggregate) in the normal weight concrete mixtures with equal volume of the chemically coated crushed polystyrene granules.

D. logeshwari et al (2022) in this construction world, Geopolymer concrete is a special concrete which doesn't requires the Ordinary Portland Cement and also reduces the emission of carbon-di-oxide. Geopolymer Concrete (GPC), an ecofriendly material is being used as an alternative to Ordinary Portland Cement Concrete in many areas. The Geopolymer Concrete is made up of industrial by-products (which contains more Silica and Alumina) and activated with the help of Alkaline solution (combination of sodium hydroxide & sodium silicate or potassium hydroxide & potassium silicate). Geopolymer concrete makes 90% utilization of fly ash and 10% utilization of iron slag powder in concrete along with alkaline solutions, as a binder. The specimens are casted for 10M, 14M and 16M of NaOH and alkaline to fly ash + iron slag powder with using superplasticiers. Hardened properties: The compressive strength, flexural test, spilt tensile strength of specimens are casted and testing as compared to 10M, 14M and 16M at 7, 14 and 28 days.

Cui et al. (2020) conducted experiments and statistical evaluations of the mechanical properties of geopolymer concretes. Conducted experiments and statistical evaluations of the mechanical properties of geopolymer concretes, here are some typical steps and analysis methods that might have been involved. Choosing geopolymer precursors (e.g., fly ash, slag, metakaolin) and alkaline activators (e.g., sodium hydroxide, sodium silicate). Formulating different geopolymer mixes based on binder content, curing temperature, and activator-to-binder ratio. Casting test specimens such as cubes, cylinders, or prisms for compressive strength, tensile strength, flexural strength, and modulus of elasticity tests. Calculating mean, median, standard deviation, and coefficient of variation to understand the spread and average behavior of the concrete properties. If multiple variables are involved (e.g., different curing temperatures, activator ratios), ANOVA can be used to identify significant differences in mechanical properties. To develop empirical models predicting the mechanical properties based on mix design variables, curing conditions, and time. Statistical methods like Design of Experiments (DOE) or response surface methodology could be used to optimize the mix proportions for the best mechanical performance. Testing hypotheses on whether geopolymer concrete exhibits statistically significant improvements in strength compared to conventional Portland cement concrete.

Imtiaz et al. (2020) reviewed contemporary trends and progress in eco-friendly geopolymer concrete, emphasizing its superior mechanical performance and durability. Their work highlighted GPC as a sustainable alternative to OPC concrete. However, they noted that the uninterrupted supply of industrial and agricultural waste materials is critical to further promoting GPC as a viable substitute for OPC.

Gambo et al. (2020) investigated metakaolin-based GPC exposed to high temperatures ranging from 200°C to 800°C in increments of 200°C. Their results showed significant losses in compressive strength—59.69% at 600°C and 71.71% at 800°C. Additionally, the specimens exhibited increased water absorption and reduced abrasion resistance at elevated temperatures.

Despite these contributions, the reviewed literature lacks comprehensive studies examining the mechanical properties of geopolymer concrete made from diverse cementitious materials, specifically combinations of fly ash and GGBS. This research area is crucial for promoting environmentally-friendly construction practices and advancing economic development within the construction industry.

Consequently, further investigations are necessary to develop enhanced geopolymers with improved mechanical properties. To address this research gap, the present study focuses on an experimental approach aimed at advancing the understanding and performance of geopolymer concrete.

Nandi Reddy Madhuri Reddy et al (2019) for the construction of any structure, Concrete is the mostly used material. Concrete usage around the world is second after water(V. M. Malhotra, 2000). The main ingredient to produce concrete is Portland cement. On the other side global warming and environmental pollution are the biggest menace to the human race on this planet today. The education of cement means the production of pollution because of the emission of CO2 during its production (D.M. J. Sumajouw, 2007). There are two different sources of CO2 emission during cement production. Combustion of fossil fuels to operate the rotary kiln is the largest source and other one is the chemical process of claiming limestone into lime in the cement kiln also produces CO2. India which is the second largest cement manufacturer world wise reports almost 150 MT of CO2emissions in 2015(R. M. Andrew, 2017). The cement industry contributes about 5% of total global carbon dioxide emissions. And also, the cement is manufactured by using the raw materials such as lime stone, clay and other minerals. Quarrying of these raw materials also causes environmental degradation. To produce 1 ton of cement, about 1.6 tons of raw materials are re - quire and the time taken to form lime stone is much longer than the rate at which humans use it. But the demand of concrete is increasing day by day for its ease of preparing and fabricating in all sorts of convenient shapes. So to overcome this problem, the concrete to be used should be environmental friendly.

Supraja and Rao (2016) studied the application of Ground Granulated Blast Furnace Slag (GGBS) as a complete replacement for Portland cement, where the binding agents were alkaline liquids, specifically sodium silicate and sodium hydroxide. The researchers examined the effect of varying sodium hydroxide molarities—3M, 5M, 7M, and 9M—on the geopolymer concrete (GPC). Their findings revealed that the compressive strength of the geopolymer increased with higher molarity levels of sodium hydroxide.

Smita Singh (2016) demonstrated in her research that red mud has the potential to be used as a source material in geopolymer concrete, similar to fly ash, rice husk ash, and GGBS, by employing an ambient temperature curing method. The experimental results showed good strength and desirable setting times. It was also noted that grinding red mud and fly ash to a particle size of 45 µm enhanced these properties.

V. Gurusaktivel et al. (2016) highlights several key conclusions regarding geopolymer concrete. Geopolymer concrete shows promising improvements in strength, durability, and sustainability, with economic and environmental benefits, particularly in reducing CO_2 emissions and enhancing the longevity of concrete infrastructure.

Shear and Flexural Capacity: The shear and moment capacities of the geopolymer concrete sections were found to be similar, which led to combined shear and flexural cracking during beam testing. This suggests that both shear and flexural forces contributed equally to the failure of the beam, making the material behavior complex under loading.

Environmental Benefits: Geopolymer concrete, made using low-calcium fly ash, offers significant environmental benefits. It has the potential to substantially reduce CO_2 emissions compared to ordinary Portland cement (OPC) due to the absence of the high-temperature clinker production process in geopolymerization. The reduction in greenhouse gases can be as much as 90% compared to OPC, making it an environmentally friendly alternative.

Durability: Geopolymer concrete is noted for its durability, with the potential to create infrastructure with a service life measured in hundreds of years. This is largely due to the material's superior resistance to aggressive environmental conditions such as chemical attacks and high temperatures.

Effect of KOH Concentration: The shear and flexural strengths of geopolymer concrete increase with the concentration of potassium hydroxide (KOH). The study found that increasing the KOH concentration from 10M to 14M resulted in higher shear and flexural strength. This is likely due to the stronger bonding between the alkali activators and the silicate material in the geopolymer.

Silicate to Potassium Hydroxide Ratio: The ratio of silicate to potassium hydroxide liquid by mass was found to be another important factor influencing the strength of geopolymer concrete. A higher ratio of silicate to KOH resulted in increased strength, indicating that the chemistry of the activator plays a critical role in the performance of the geopolymer.

Ning Liu et al. (2016) explored the influence of Expanded Polystyrene (EPS) particle size on the mechanical properties of EPS lightweight concrete. EPS concrete is a type of lightweight concrete that incorporates EPS beads as aggregate, which helps in reducing the overall weight of the material while maintaining reasonable mechanical properties. The study further recommended selecting an optimal EPS particle size to balance the desired mechanical properties, cost, and lightweight characteristics of the concrete. This type of concrete has potential applications in construction, particularly in situations where reduced structural weight is essential, such as in the construction of high-rise buildings and other structures where weight reduction contributes to overall efficiency and cost savings.The findings of the study indicated that the particle size of EPS significantly affects the mechanical performance of the concrete. The results suggest that:

Smaller EPS particles typically lead to higher compressive strength and improved bonding with the cement matrix, which enhances the overall mechanical properties of the concrete.

Larger EPS particles, on the other hand, tend to reduce the strength of the concrete, as they create larger voids and reduce the interaction between the EPS particles and the cement binder, leading to decreased load-bearing capacity.

The study also observed that modulus of elasticity, flexural strength, and durability were influenced by the size of EPS particles, and optimal performance was achieved at a certain particle size.

Anwar Hosan et al. (2016) provides an in-depth comparison of sodium (Na) and potassium (K) based fly ash geopolymer pastes at elevated temperatures. The Na-based geopolymer showed higher compressive strength at both ambient temperature and up to 400°C compared to the K-based geopolymer. At 600°C, the K-based geopolymer exhibited slightly higher compressive strength than the Na-based geopolymer. The K-based geopolymer demonstrated higher residual compressive strengths at elevated temperatures, as well as at ambient temperature, compared to the Na-based geopolymer. Specifically, the K-based geopolymer with a K2SiO3/KOH ratio of 3 showed the highest residual compressive strengths at all elevated temperatures. The K-based geopolymer exhibited better volume stability, but it experienced higher mass loss compared to the Na-based system. The K-based geopolymer showed fewer surface cracks than the Na-based system at elevated temperatures. This research highlights the potential of K-based activators, particularly for applications requiring durability at high temperatures, as it not only demonstrates superior residual strength but also fewer cracks and improved volume stability at elevated temperatures.

Kamlesh Patidar et.al (2014**)** the study by discusses the key components of geopolymer concrete. Geopolymer concrete is made from two primary ingredients: source materials and alkaline liquids the source materials used in geopolymer concrete are alumina-silicate-based materials, rich in silicon and aluminum. These materials include natural minerals like kaolinite and clays, as well as industrial by-products like fly ash, silica fume, slag, and rice husk ash. The choice of source material depends on factors such as availability, cost, the type of application, and user preferences. The alkaline liquids used in geopolymer concrete are typically sodium or potassium-based alkali metals. These are created by combining sodium hydroxide or potassium hydroxide with sodium silicate or potassium silicate. This results in an alkaline solution that plays a crucial role in the geopolymerization process. The geopolymerization process occurs when the source materials (such as fly ash) react with the alkaline liquids (such as sodium hydroxide and sodium silicate). This chemical reaction forms a gel-like substance that binds the fine and coarse aggregates together, creating a hardened concrete structure. This process makes geopolymer concrete a cement-free alternative, using fly ash as a binder in place of traditional Portland cement. Geopolymer concrete is a sustainable and environmentally friendly alternative to conventional concrete, utilizing industrial by-products and alkali activators to form a strong binding gel that holds aggregates together.

Andi Arham et al. (2014) highlighted the significant influence of temperature and curing duration on the strength development of fly ash-based geopolymer mortar. The researchers concluded that the optimal heat curing regime for maximizing the strength of the mortar was achieved at a temperature of 120°C for a duration of 20 hours. This finding suggests that proper curing conditions are essential for improving the mechanical properties of geopolymer mortars, particularly those based on fly ash, which require elevated temperatures to activate the geopolymerization process effectively.

S. V. Patankar et al. (2014) on the mix design steps for the preparation of geopolymer concrete addresses several key parameters critical to the formulation and optimization of geopolymer concrete. The parameters considered in their mix design include

*Fineness of Fly Ash***:** The particle size distribution and fineness of the fly ash play a significant role in determining the reactivity of the material. Finer fly ash particles increase the surface area for the chemical reactions, enhancing the strength and durability of the geopolymer concrete.

*Wet Density of Concrete***:** This refers to the density of the fresh geopolymer concrete mixture before it hardens. It is essential to ensure that the wet density matches the required design strength and workability.

*Solid Content of Alkaline Solution***:** The solid content refers to the amount of active alkaline substances in the solution that reacts with the fly ash to form the geopolymer binder. The concentration of the alkaline solution directly affects the geopolymerization process.

*Concentration of Alkaline Solution***:** The concentration of the alkaline solution (typically a mix of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3)) is a critical factor in controlling the geopolymerization reaction. A higher concentration leads to faster setting times and increased strength, but care must be taken to prevent an overly rapid reaction.

*Alkaline Solution Ratio***:** The ratio of the alkaline solution to the fly ash is crucial for achieving the desired workability and strength. This ratio must be carefully controlled to avoid excess moisture or insufficient chemical activation.

*Quantity of Water***:** The amount of water used in the mix influences the workability, consistency, and curing process. The water content must be optimized to maintain the right balance between fluidity and strength.

*Fine and Coarse Aggregate Content***:** The proportion of fine and coarse aggregates affects the mix's density, strength, and workability. The aggregates should be selected and graded appropriately to meet the specifications of the project.

*Geopolymer Binder to Water Ratio***:** This ratio is crucial in determining the final strength and durability of the geopolymer concrete. A lower binder-to-water ratio typically results in higher strength and durability.
The successful preparation of geopolymer concrete involves optimizing these parameters to achieve the desired workability, setting time, strength, and durability while minimizing environmental impact by reducing the use of Ordinary Portland Cement (OPC).

METHODOLOGY :

Study focuses on *Geopolymer Concrete (GPC)* prepared with *fly ash, fine aggregate, coarse aggregate, alkaline solution, and steel slag*. The primary goal is to investigate the properties of these materials and evaluate the *compressive strength* of the specimens under *ambient curing* and *sunshine curing* with varying proportions of *steel slag* and *fly ash*. Geopolymer concrete in this study is developed using *fly ash***,** *fine aggregate***,** *coarse aggregate***,** *alkaline solution*, and *steel slag* as primary materials. Crushed stone or gravel with varying sizes ensures proper load transfer and structural stability. Facilitates the polymerization process by dissolving aluminosilicate precursors in fly ash. Enhances strength and abrasion resistance due to its high density and stiffness. Promotes recycling of industrial by-products like *fly ash* and *steel slag*. Utilizes waste materials, minimizing landfill disposal and promoting green construction practices.

CONCLUSION :

Iron powder slag can be effectively integrated into *geo polymer concrete* to produce *high-strength, durable, and eco-friendly materials***.** Its application supports *waste valorization* and *sustainability goals*, particularly in *infrastructure and industrial construction***.** Further research can focus on long-term *durability tests* and *cost optimization* to expand its practical use. Experiment is focused on exploring the potential of using steel slag as a partial replacement for fine aggregates in ash-based geopolymer concrete. This approach is aimed at improving the strength properties of the material, including compressive, tensile, and flexural strength. Based on your findings, replacing

REFERENCES :

1. Xin Cai, Zihao Cao, Zihao Cao "Influence of Iron Slag on Properties of Cement-Based Materials: A Review" 17 August 2024 / Revised: 15 September 2024 / Accepted: 17 September 2024 / Published: 20 September 2024 https://doi.org/10.3390/buildings14092985

2. Zhengyi Ren , Dongsheng Li "Application of Iron Slag as an Aggregate in Concrete Production: A Review" 2023 Aug 25;16(17):5841. doi: 10.3390/ma16175841

3. Rahul D. Pawara, Bhavana V. Chavan "Experimental Investigation Flyash Based Light Weight Geopolymer Concrete Using Expanded Polystyrene (EPS) : A Review" International Journal of Research Publication and Reviews, Vol 3, no 5, pp 3435-3437, May 2022 Journal propertypage: www.ijrpr.com ISSN 2582-7421

4. D. logeshwari1, B. Kiruthika "an experimental study on fly-ash and iron slag powder based geopolymer concrete" International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 09 Issue: 06 | Jun 2022 www.irjet.net p-ISSN: 2395-0072.

5. Nandi Reddy Madhuri Reddy1 ,Smt. G. Bhagyamma "a study on strength of steel slag incoporated lowcalcium flyash based geopolymer concrete" 2019 JETIR June 2019, Volume 6, Issue 6 www.jetir.org (ISSN-2349-5162) JETIR1907V14 Journal of Emerging Technologies and Innovative Research (JETIR) www.jetir.org

6. Abdul Alee et al (2012), Geopolymer Concrete- A Review, International Journal of Engineering Sciences & Emerging Technologies, Volume 1, pp.118-122.

7. Abu Muhammad and Nidhin B. Parappattu (2015), ‘Study on Performance of Fibre Mesh Reinforced Slabs’, International Journal of Science Technology & Engineering, vol 2, pp.22- 27.

8. Arun Kumar et al 2017, 'Experimental Study on Impact Resistance of Geopolymer Ferrocement Flat Panel', International Study on Impact Resistance of Geopolymer Ferrocement Flat Panel', pp.1-5

9. A.Z. Waridwazien et al 2016, ‘Strength and density of Geopolymer Mortar Cured at Ambient Temperature for Use as Repair Material’, IOP Conference Series: Materials Science and Engineering, pp. 1-6

10. Basil M. Mali and Renjan Abraham 2016, ‘Study on Geopolymer Concrete Used For Paving Blocks’, International Journal of Innovative Research in Advanced Engineering (IJIRAE), Volume 3, pp.62-66.

11. Brett Tempest et al 2009, 'Compressive Strength and embodied Energy Optimization of Fly-ash based Geopolymer concrete', World of Coal ash Conference, pp.1-17

12. Shrikant M. Harle (2017), ‘Effect Of Curing Period, Rest Period And Mix Proportion On Geopolymer Concrete’, Journal of Research in Engineering and Applied Sciences, Vol. 2, pp.105- 109