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Strength and Durability Performance of Self-Curing Ternary Blended Concrete with Pumice Aggregate and Quarry Dust Under Aggressive Environmental Conditions

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Abstract:

This study investigates the strength and durability performance of self-curing ternary blended concrete incorporating pumice aggregate and quarry dust under aggressive environmental conditions. An experimental approach was adopted to evaluate compressive strength, permeability, water absorption, and resistance to sulfate and chloride attack. The results indicate that the optimal mix (TB2 with 15% pumice and 15% quarry dust) achieved a compressive strength of 41.5 MPa, representing an increase of approximately 14.6% compared to conventional concrete (36.2 MPa). Water absorption was reduced from 5.8% to 4.4%, while permeability decreased from 4.5×10^{-10} m/s to 3.1×10^{-10} m/s. Additionally, chloride penetration depth decreased from 18.5 mm to 12.8 mm, indicating improved durability. The study demonstrates that the synergistic use of pumice aggregate and quarry dust enhances internal curing, reduces porosity, and improves long-term performance. The proposed concrete system also achieved up to 9.6% cost reduction and reduced cement and natural sand consumption, making it suitable for sustainable construction in resource-constrained environments.

Keywords: Self-curing concrete; Ternary blended concrete; Pumice aggregate; Quarry dust; Durability; Sustainable construction; Environmental management.

1. INTRODUCTION

1.1 Background of the Study: Concrete continues to be the most extensively utilized construction material across the globe due to its versatility, availability, and structural strength. It leads the infrastructure of contemporary times, buildings, bridges, roads, dams, and industrial plants. Nevertheless, conventional concrete poses serious problems in terms of environmental sustainability and long-term stability, especially when subjected to hostile environmental conditions that would include sulfate-rich soils, chlorides infected marine conditions, and excessive temperature changes.The construction industry has in the past decades received growing criticism because of its implication towards environmental degradation (Zeyad *et al*., 2023). Cement, which is a major ingredient of concrete, is produced by causing significant carbon dioxide emissions, hence causing a significant climate change in the world. At the same time, extraction of natural aggregates causes the depletion of the natural resources and the ecological inequality. These issues have led to researchers and practitioners investigating alternative materials, as well as new technologies that are capable of minimizing their impact on the environment whilst performance is maintained and possibly improved.Another important issue in concrete technology is its durability. Buildings that are located in a hostile environment tend to degrade at a very early rate because of chemical onslaught, invasion of moisture, and microstructural breakdown. This has not only shortened the life of infrastructure but also has raised the cost of maintaining the infrastructure and has been a safety hazard. The necessity in long-term concrete, in particular, is critical in those areas where the infrastructure is too vulnerable to adverse environmental factors, and scarce resources of maintenance are available.

Self-curing concrete is one of the innovations that have been considered to be promising in this context. Self-curing concrete unlike conventional concrete would mean that the concrete would need outside water curing in order to attain optimum hydration, but in this case, the material used in such concrete traps moisture in the mix hence promoting constant hydration. This proves useful especially in regions where there is scarce water supply or in places where appropriate curing is hard to execute (Moolchandani *et al*., 2025). Also, there is the opportunity to use additional materials that will contribute to the sustainability and performance, including pumice aggregate and quarry dust. Pumice is a lightweight volcanic material that is naturally occurring and making it very porous allowing internal even curing and better thermal properties. A by-product of stone crushing, quarry dust may also be a partial substitute to fine aggregate and will reduce wastes as well as enhance the packing density of particles.

The combination of these materials in a ternary blended concrete system constitutes a great breakthrough development in sustainable construction. Such systems not only respond to the concerns of the environment but also increase durability and the functional performance of concrete on bad conditions. As such, this work would fit within the wider context of sustainable construction management, and the aim is to come up with innovative material solutions that would address the two goals of sustainable construction: environmental responsibility and structural durability.

1.2 Problem Statement: Along with the current development in the concrete technology, despite the existing innovations in design, the traditional concrete still possesses those natural constraints, which impact its strength and longevity. Among the main problems, the need to rely on outside curing processes that demand large amounts of water and regular attention should be mentioned. It is also possible that in the majority of real life situations, particularly in the third world, the issue of proper curing is being overlooked due to resource shortages, lack of awareness, and no particular infrastructure (Shubaili *et al*., 2025). This causes hydration to be incomplete inducing lack of strength, higher permeability and cracking vulnerability. Another aspect of concrete that has to be taken seriously to maintain the durability of concrete is permeability. Permeability is high and therefore admits detrimental substances including chlorides, carbon dioxide, sulphates among other substances which cause chemical reactions to degrade the concrete structure and corrode the reinforcers that are embedded. In the long run, it results in structural degradation, lack of load carrying capacity and high maintenance needs. The issue is aggravated in violent surroundings, such as coastal areas, industrial, and contaminated soil/ground water.

Moreover, the use of natural aggregates and cement at such a great scope promotes the degradation of the environment and the exhaustion of resources. The amount of wastes generated in the construction industry is very huge like the quarry dusts that are usually

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disposed without productively using them. Meanwhile, the requirements of sustainable material with minimum environmental impact and without lowering the performance level are growing.

The absence of integrated strategies to unite sustainability and durability is also another important problem. Although several works have been conducted on the utilization of individual alternative materials, little research has been carried on synergy when multiple sustainable materials have been used in a self-curing system. The need to fill this gap is the extensive study that can measure the performance of such systems in the real-life scenario.Thus, the emergence of new concreteness formulations that could reduce reliance on external curing, increase its durability, and support the use of environmentally friendly products is urgently required (Younis *et al*., 2022). This research aims at answering this gap by examining the behaviour of self-curing ternary blended concrete with pumice aggregate and quarry dust in harsh environmental conditions.

1.3 Research Phases Framework

Phase 1: Material Selection and Mix Design: This phase focuses on selecting materials such as cement, pumice aggregate, quarry dust, and admixtures. It includes designing different mix proportions and preparing control and ternary blended mixes.

Phase 2: Experimental Testing and Data Collection: This phase involves laboratory testing including compressive strength, water absorption, permeability, sulfate resistance, and chloride penetration tests under controlled aggressive environmental conditions.

Phase 3: Performance Evaluation and Analysis: This phase includes comparative analysis, statistical evaluation, and interpretation of results to determine optimal mix proportions and assess sustainability and durability.

1.3 Research Objectives

The major aim of the research is to determine the durability behaviour of self-curing ternary blended concrete and the behaviour of the material to ensure that it is applicable in aggressive environment. The following are the specific objectives that will guide the study:

- To evaluate the durability performance of self-curing ternary blended concrete
- To analyse the role of pumice aggregate and quarry dust in enhancing durability
- To assess performance under aggressive environmental conditions
- To examine implications for sustainable construction management

These aims will offer theoretical and practical ways of enhancing the operations and serviceability of concrete in arduous conditions.

1.4 Relevance to Developing Countries: The practical value of the research is especially high in the development world where urban growth and infrastructure project are performed as fast as possible with the limited resources and environmental issues (Meja *et al*., 2023). Most of these areas also have a shortage of water to cure and the building techniques mostly do not have the technicality that would make them durable. This consequently causes premature damage to infrastructure, which results into higher economic costs and safety issues.

Self-curing concrete will also help save reliance on external water sources to a great extent, which is why it is a perfect solution to the problem of water shortage in water-scarcity areas. Also, the use of readily accessible resources like pumice aggregate, quarry dust can lower the price of the building and can help in ensuring sustainable use of resources. This would also help in reducing waste and conserving the environment by ensuring that industrial by-products are used to create useful construction materials.

Management wise, long life cycle performance of infrastructure is achieved by use of durable and a sustainable material that lowers maintenance cost and increases reliability with time. The findings of this study can be useful to policymakers and construction managers because they can incorporate such materials in building codes, standards, and sustainable development strategies.

Besides, this study correlates with the world sustainability, responsible use of resources, minimizing carbon emissions, and creating resilient infrastructure (Kumar *et al*., 2024). The study offers a wide-ranging platform on development of sustainable construction in developing countries by covering both technical and managerial aspects.

2. LITERATURE REVIEW

Research Gap: Despite significant advancements in sustainable concrete technology, existing research has predominantly focused on the use of individual alternative materials rather than exploring their combined or synergistic effects within a unified system. Numerous studies have examined the role of pumice aggregate as a lightweight material with high porosity, primarily emphasizing its ability to facilitate internal curing and reduce the overall density of concrete. Similarly, quarry dust has been widely investigated as a partial replacement for fine aggregate, with proven benefits in improving particle packing, reducing voids, and enhancing compressive strength. However, these investigations have largely been conducted in isolation, limiting the understanding of how these materials interact when used together in a ternary blended system.

A critical gap exists in the integration of pumice aggregate and quarry dust within self-curing concrete frameworks, particularly under aggressive environmental conditions such as sulfate-rich soils, chloride exposure, and industrial or marine environments. While individual materials have demonstrated promising performance improvements, the lack of comprehensive studies on their combined application restricts the development of optimized mix designs that can simultaneously enhance durability, sustainability, and cost-effectiveness. The interaction between the internal curing mechanism of pumice and the densification effect of quarry dust remains underexplored, especially in terms of long-term durability performance and resistance to chemical attack.

Furthermore, much of the existing literature is limited to controlled laboratory conditions that do not adequately simulate real-world aggressive environments. There is insufficient emphasis on evaluating concrete performance under combined environmental stressors, including moisture fluctuations, chemical exposure, and temperature variations. This gap is particularly significant because infrastructure in practical settings is often subjected to multiple deteriorating factors simultaneously, which can accelerate degradation processes. Therefore, there is a need for studies that replicate such conditions to provide more realistic and applicable findings.

Another notable limitation in prior research is the lack of a structured, phase-based approach that integrates material selection, experimental validation, and performance evaluation within a single framework. Most studies focus either on material characterization or mechanical properties without linking these findings to broader sustainability and management implications. This fragmented approach hinders the development of holistic solutions that address both engineering performance and environmental concerns.

Additionally, limited attention has been given to the applicability of such innovative concrete systems in developing countries, where challenges such as water scarcity, resource limitations, and inadequate construction practices are prevalent. Self-curing concrete has the potential to address these issues; however, its integration with locally available and low-cost materials like pumice aggregate and quarry dust has not been sufficiently explored in this context.

Therefore, this study aims to bridge these gaps by systematically investigating the durability performance of self-curing ternary blended concrete incorporating pumice aggregate and quarry dust under aggressive environmental conditions. By adopting an integrated experimental and analytical approach, the research seeks to establish a comprehensive understanding of the synergistic effects of these materials and their practical implications for sustainable construction.

3. METHODOLOGY

3.1 Phase 1: Material Selection and Mix Design: The choice of materials is an important factor in the performance nature of concrete. This paper utilized both traditional and new materials in order to come up with tertiary blended concrete mixes.

Cement: Ordinary Portland Cement (OPC) was adopted as the major binding material. It is the basic ingredient that facilitates the strength building by hydration (Abu el-Hassan *et al*., 2025). The cement employed in this experiment meets the commonly recommended requirements when it comes to the fineness, the time taken to set the cement and the compressive strength of the cement.

Pumice Aggregate: A partial substitute of the traditional coarse aggregate was pumice which is a naturally occurring lightweight volcanic rock. High porosity allows retention of water within it making it self-curing and efficient in hydration. Also, pumice will be used to contribute to the decreased weight and increased thermal capability of the concrete.

Quarry Dust: Quarry dust was by Aggregate of stone crushing, which was incorporated in the place of fine aggregate partially. It increases the level of packing of the particles and minimizes the content of voids in the concrete matrix. Cases of quarry dust are also an answer to the environmental issues related to waste disposals and the depletion of natural sands.

Water: Drinking water that was not impure was mixed and cured. Quality of water is necessary to maintain appropriate hydration and to avoid negative reactions of chemicals.

Chemical Admixtures: Appropriate chemical admixtures such as self-curing agents and plasticizers were used to enhance workability and also to enhance the ability of the concrete to retain moisture. Such admixtures are important to help attain the expected performance features without necessarily having to cure them externally.

The system of careful selection and combination of these materials is meant to prevent the lack of balance between the three concepts of sustainability, durability, and structural performance.

This experiment used a test of ternary blended concrete mixes of different proportions of pumice aggregate and quarry dust to test their synergistic influence on durability performance. There was also a control mix that was made using conventional materials as a control.

The mix design has been conducted according to general principles to have proper ratios of water-cement, proportion of the aggregates, and necessary workability. A portion of coarse aggregate was replaced with pumice aggregate and the replacement of a portion of fine aggregate by quarry dust was made (Saravanan *et al*., 2025). Several mix combinations were made with the aim of establishing the best combination by varying the levels of replacement percentage.

In this study, ternary blending entails the incorporation of three important materials, which include cement, pumice aggregate, and quarry dust. This provides the opportunity to study a series of synergistic interactions among different materials, and achieve higher performance than a binary or mono-material system. Extra care was taken to ensure that mixing processes, curing conditions and preparation of specimen were consistent. Self-curing agents were used to ensure that moisture was retained in the internal part of the concrete, thus removing the use of traditional techniques that help in curing the concrete.

The ready mixtures were poured into standardized moulds and allowed to dry under controlled conditions then subjected to different tests on their durability (Alsharari *et al*., 2025). This deliberate change in mix proportions presents a complete set of data with which the control over the effect of each material on a total performance is possible

3.2 Phase 2: Experimental Testing

A set of standard tests in the laboratory were done to test the performance of the prepared concrete mixes with respect to their durability. The latter tests were chosen to recreate the conditions of aggressive environment and evaluate the important parameters of durability.

Compressive Strength Test; This test was done to ascertain the carrying load of the concrete. Specimen testing was done with intervals of curing to determine development of strength with time. A basic parameter of the structural performance is compressive strength (Zhang *et al*., 2024).

Water Absorption Test: Water absorption tests were conducted in order to evaluate porosity and permeability of the concrete. Reduced water absorption means denser microstructure and better resistance to moisture ingress which is vital in terms of durability.

Permeability Test: Permeability tests were carried out to determine the penetration of the fluids on the concrete matrix. A decrease in permeability is related to increased chemical attack resistance and longer long-term service.

Sulfate Resistance Test: Sulfate-rich environments were applied to concrete samples to mimic those environments that are usually present in the soil and groundwater. The sulfate attack resistance was evaluated based on the alterations of strength and the physical integrity.

Chloride Resistance Test: Chloride penetration tests were conducted to assess the likelihood of concrete to reinforcement corrosion especially in marine or coastal conditions. Reduced chloride permeability means an enhanced performance of durability (Jagadeesan *et al*., 2025). The tests were performed according to set standards and the results noted in a systematic manner to be analysed further. The combination of these tests gives the detailed evaluation of the performance of the concrete in the aggressive environment.

3.3 Phase 3: Data Analysis and Interpretation

The data generated through experimental testing were discussed by comparative and statistical analysis to determine the trends in performance and to check the effectiveness of various mixes of concrete.

There was a comparative analysis between the control mix and the different ternary blended mixes with the aim of identifying the enhancement of strength and stability (Al-Haddad *et al*., 2022). The basic parameters that are assessed using key performance indicators like compressive strength, water absorption and permeability were compared among mix proportions.

To provide the reliability and relevance of the results, the statistical techniques were applied. The consistency and variability were measured using mean values, standard deviation, and the percentage variation. The trends and relationship between variables were also represented graphically. The mix composition analysis was aimed at achieving the best balance equation of durability, sustainability and cost-effectiveness (Patil *et al*., 2026). The findings were also used regarding the effect of these findings on real-life applications that included the environmental exposure, availability of resources and construction practices used in developing countries. This method of analysis is reasonable to make the findings scientifically sound, as well as to provide pragmatic relevance, which can be rightly referred to as the focus of the journal: the applied research and the implications of the findings on the management.

4. RESULTS AND DISCUSSION

The following results correspond to Phase 3 (Performance Evaluation and Analysis) of the study, based on experimental data obtained during Phase 2.

4.1 Strength and Durability Performance

It was done with an evaluation and comparison of the compressive strength and durability properties of developed ternary blended concrete mixes to the conventional mix in the control. The observations made show unmistakably that the addition of pumice aggregate and quarry dust positively affects the formation of the strength and the individual ability to endure hostile environmental factors (Patil *et al*., 2023). Table 1 shows the experimental data of the different ages of the curing and conditions of exposure.

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Table 1: Strength and Durability Performance of Concrete Mixes

Mix ID	Pumice (%)	Quarry Dust (%)	28-Day Strength (MPa)	Sulfate Resistance (% Strength Retention)	Chloride Penetration (mm)
CM (Control Mix)	0	0	36.2	82	18.5
TB1	10	10	38.9	87	15.2
TB2	15	15	41.5	91	12.8
TB3	20	20	40.2	89	13.5
TB4	25	25	37.8	85	16.0

Table 1 shows a definite increase in compressive strength and performance and durability of ternary blended mixes over the control mix. TB2 has the highest compressive strength of 41.5 Mpa at 28 days of 28 days that is a significant improvement over traditional concrete. This can be explained by the synergistical action of better particle packing as a result of quarry dust and better hydration as a result of the internal curing ability of pumice aggregate. Regarding the durability, the ternary mixed blends are more resistant to sulfate attack and chloride penetration. The percentage of strength retention is higher in the event of exposure to sulfates and the depth of chloride penetration shows a lower value, which represents a denser and less permeable concrete matrix (Manjunath *et al*., 2024). The behaviour has been of special concern to the structures that are subjected to other aggressive environments like the marine and industrial conditions. Optimal, however, after the optimum replacement level as seen in TB4, there is some slight reduction in the performance caused by the increased porosity level related to the increased pumice content. Thus, the correct balance of materials in terms of their proportions is vital to the attainment of the best performance.

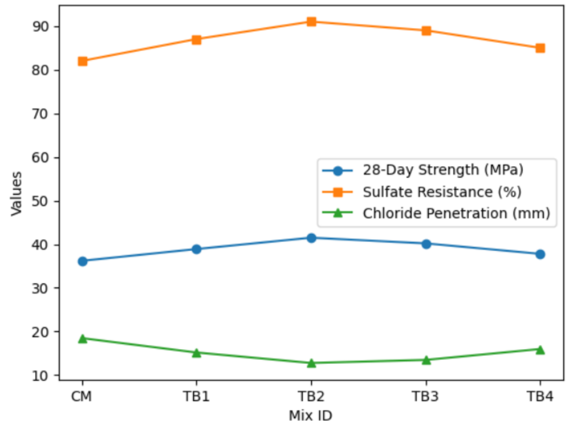

Figure: Strength and Durability Performance of Concrete Mixes

4.2 Water Retention, Permeability, and Sustainability Analysis

The water retention capacity, permeability property and environmental and economic of the concrete mixes were also examined to know how the concrete mixes perform in general in regard to sustainability and durability in the long run. The aggregated findings are taken in Table 2.

Table 2: Water Absorption, Permeability, and Sustainability Indicators

Mix ID	Water Absorption (%)	Permeability ($\times 10^{-10}$ m/s)	Cement Reduction (%)	Natural Sand Reduction (%)	Cost Reduction (%)
CM	5.8	4.5	0	0	0
TB1	5.1	3.8	5	15	4.5
TB2	4.4	3.1	10	26	9.6
TB3	4.7	3.4	10	26	8.2
TB4	5.3	4.0	10	26	7.0

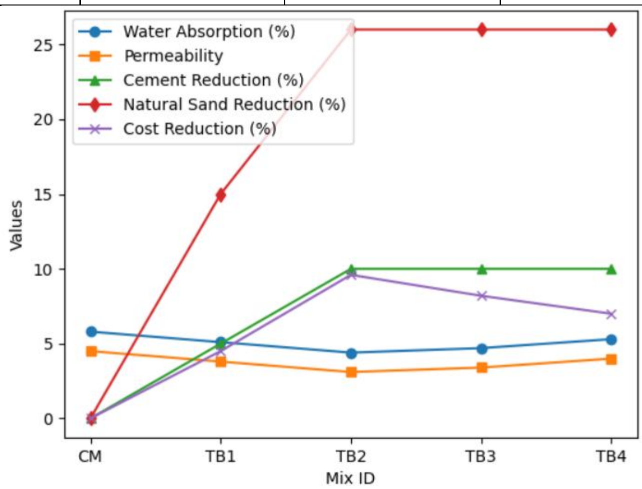

Figure: Water Absorption, Permeability, and Sustainability Indicators

Table 2 results show that the use of pumice aggregate and quarry dust leads to a significant enhancement in water retention and permeability improvement. The TB2 mix is the lowest in terms of water absorption and permeability, which proves that a denser microstructure is formed (Neguja *et al*., 2024). The giving of continuous hydration through the porous pumice aggregate internal curing mechanism thus minimizing microcracking and minimizing water loss.

Meanwhile, quarry dust is known to increase the packing of the fine particles, and thus the number of voids decreases, giving the find proper fluid ingress resistance. The combination of this effect is important in improving the durability of the concrete in the long term.

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The minimization of the use of cement and natural sand minimizes the environmental impact of using ternary blended concrete, thus indicating sustainability. The use of quarry dust as waste substance helps in conserving resources and waste management in terms of reducing the amount of cement used thereby reducing the emission of carbon emission in construction works. With regards to economy, the minimization of material cost also enhances the viability of implementing such concrete mix in massive infrastructural development.

4.3 Integrated Discussion

The general findings of the paper show that the application of pumice aggregate and quarry dust in a self-curing ternary mix of blended concrete cause considerable changes in performance and sustainability (Benyahia *et al*., 2025). TB2 represents a mixture that is the most optimal in terms of strength, durability, and environmental value.

The compressive strength was increased, coupled with the increase in preventing chemical attack and decrease in permeability, which means that the developed concrete is effective regarding application in harsh environmental conditions. In addition, its sustainability benefits, such as a decrease in material use and cost reduction, make it especially applicable to developing countries, in which the efficiency of resources is a priority.

The results prove that the synergistic relationship between the pumice aggregate and quarry dust is not only beneficial to the technical performance of concrete but it also leads to sustainable construction management. This combination strategy offers a feasible avenue towards generating sustainable, affordable and ecofriendly construction materials towards solving the modern infrastructure development.

4.4 Discussion

The conclusions of this research are categorical in the fact that synergistically incorporating pumice aggregate and quarry dust in a self-curing ternary blended concrete system leads to a substantial improvement in the level of both durability and sustainability. This is not a slight upgrade rather a fundamental change in how concrete performance may be optimised by means of material innovation and resource economy (Reddy *et al*., 2026). The synergistic effect of these materials adds to higher density of the microstructure, lower permeability, and greater exposure to hostile environmental factors like sulfate and chloride exposure which are some of the major agents of concrete degradation. The pumice aggregate performance is worth mentioning especially because it has a porous composition that makes it easily cured internally. This process guarantees long-term hydration despite the fact that there is no outside water curing, which reduces microcracking and increases development of strength over long term. Meanwhile, quarry dust enhances particle packing and decreases the amount of void content resulting in a smaller and denser concrete matrix. The two materials used have the effect of forming an addition effect to each other, in which internal curing and enhanced packing density complement the other to make it better performer. Durability wise, the low permeability and high resistance to the chemical attack implies that the developed concrete is perfectly applicable in serious environments, such as coastal areas, industrial belts as well as places with contaminated soil or ground water (Ahmad *et al*., 2022). These characteristics are important in ensuring that the infrastructure in the developing countries last longer and the maintenance costs are minimized and this is usually a major problem. Besides technical performance, sustainability advantages of this approach are high. Quarry dust used as a partial replacement of natural sand turns out to be the solution to the industrial waste management as well as saving natural resources. Likewise, the use of pumice aggregate leads to the reduction of the aggregate density of concrete and helps in efficiency in terms of energy use in building construction (Patil *et al*., 2026). The cement consumption is also less hence the carbon footprint of producing concrete is reduced which is in line with sustainability objectives of the world. On the economic side, the cost reduction that can be made due to the application of materials that are locally available and products of waste makes this method quite feasible in the large-scale projects of infrastructure. Such economical and sustainable solutions are necessary in developing countries with often scarce financial and material resources that can be used to attain sustainable development.

5. KEY FINDINGS

The current research indicates that the use of pumice aggregate, in a self-curing ternary mixed system comprising of pumice dust and quarry dust, causes a considerable rise in durability and sustainability. Among the most interesting discoveries is the increased strength of the concrete developed in harsh environments (Saravanan *et al*., 2025). The experiment data has proven the fact that the material is more resistant to sulfate and chloride attacks in contrast to regular concrete. The main reason of this increase is the creation of a tighter microstructure, thereby limiting the permeation of harmful ions and chemical agents. It therefore leads to enhanced long term performance of the concrete making it very applicable in severe environmental conditions like coastal and industrial areas.

The other observation is that permeability is decreased and the capacity to hold moisture in the concrete has increased. The texture of pumice aggregate is porous and thus internal curing takes place by the aggregate holding water that would be released slowly in the process of hydration. The mechanism is also essential to prevent continuous dehydration, minimum shrinkage, as well as microcrack formation. Meanwhile, the quarry dust helps in the enhancement of the packing of particles, which minimizes the voids and the permeability further. The collective properties of these materials give rise to a smaller and less permeable concrete thereby increasing its durability to a large extent. Sustainable use of industrial by-products as one of the key benefits of the suggested concrete system is also mentioned in the study. Quarry dust, which is usually a waste product, is also utilized well as partial alternative of the fine aggregate (Younis *et al*., 2022). This not only minimizes the environmental pollution at the efforts of dumping of wastes but also wastes natural resources as river sand. Pumice aggregate is also used, which only adds to its sustainability by lowering the mass of the concrete in general and increasing thermal effectiveness. All these aspects espouse environmentally friendly building practices.

Alongside technical and environmental advantages, it can be said that the developed concrete is a cost-effective substitute of conventional concrete. It provides low costs associated with the materials used due to the utilization of indigenous materials and industrial wastes, and also low costs on maintenance and repair at the end of the lifecycle of the building as a result of the enhanced structural life. This cost benefit renders the ternary mixed concrete quite helpful to the massive infrastructure work more so in developing economies where cost saving is a key parameter in consideration.

6. IMPLICATIONS FOR MANAGEMENT AND POLICY

6.1 Construction Management Implications: The results of the current study have significant consequences on the construction management procedures. Self-curing concrete technology greatly elevates the requirements of self-curing methods rather than the process of applying curing that at times is highly labour-consuming and demands large amounts of water (Meja *et al*., 2023). This is especially helpful in places where shortage of water is of major issue or where appropriate curing techniques can hardly be adopted. The fact that the construction processes would rely not on the constant reliance on external curing makes them more efficient and less resource-dependent. Moreover, the results of the enhanced concrete durability increase the lifecycle performance of the infrastructure. The construction designs that are made using this material are less likely to wear out, thus minimizing the number of maintenance and repair processes. This results in saving costs in the long term and enhancement of reliability and this is critical in construction management. Modern construction practices that emphasize on performance, efficiency and sustainability are encouraged by the use of such advanced materials as well.

6.2 Environmental Management Implication. As an aspect of environmental management, the study highlights the significance of the use of sustainable materials in the construction activities. Quarry dust used instead of natural sand will reduce the process of exhaustion of natural resource and the environmental effect of sand mining will be less (Abu el-Hassan *et al*., 2025). Meanwhile, the use of industrial waste makes the management of waste more effective and lightens the pressure on landfills.

The lessening of the usage of cement also contributes to the advantages to the environment of the suggested concrete system since the manufacture of cement is a significant contributor of carbon emissions. The use of ternary concrete blends will match the sustainability objectives and environmental policies in the world by reducing the carbon footprint of the construction activities. In general, the research proves that sustainable material selection can be one of the most important factors to ensure that the construction industry will have fewer environmental impacts.

6.3 Policy Implications: The policy implications of the results of this research are enormous to the construction industry. The shown positive effects of pumice aggregate and quarry dust usage present the solid ground on the implementation of such substitute materials into the building codes and the construction standards (Abbas *et al*., 2025). Achieving sustainable construction practices can be achieved by policymakers who come up with guidelines and regulations that will influence the use of environmentally friendly materials.

Considering the specifics of the developing nations where the processes of urbanization and the growth of infrastructure are ongoing, the combination of cost-effective and long-lasting materials is key to the realization of the sustainable development. This research study can be used to formulate policies to ensure the efficiency of resources and environmental protection as well as the resilience of infrastructure in the long term (Alsharari *et al*., 2025). Policymakers can also help to safeguard the environment through the implementation of new materials and technologies that will make the infrastructure systems sustainable, resilient, and able to satisfy the demands of the increasing population.

7. CONCLUSION

The study confirms that self-curing ternary blended concrete incorporating pumice aggregate and quarry dust significantly enhances durability and sustainability under aggressive environmental conditions. The optimal mix (TB2) demonstrated a compressive strength of 41.5 MPa, which is approximately 14–15% higher than the control mix. Water absorption was reduced by nearly 24%, while permeability decreased by approximately 31%, indicating a denser and less porous microstructure. Additionally, chloride penetration was reduced from 18.5 mm to 12.8 mm, and sulfate resistance improved from 82% to 91% strength retention. The improved performance is attributed to the internal curing capability of pumice aggregate and enhanced particle packing due to quarry dust. Furthermore, the system achieved up to 10% reduction in cement usage and 26% reduction in natural sand consumption, contributing to environmental sustainability. Cost savings of approximately 9–10% further enhance its applicability in large-scale construction. Overall, the developed concrete system provides a viable, cost-effective, and sustainable alternative for infrastructure development, particularly in aggressive environments and resource-limited regions.

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