Policy Research Journal
ISSN (E): 3006-7030 ISSN (P) : 3006-7022 Volume 4, Issue 2, 2026

EFFECT OF WASTE PUMICE AGGREGATE ON DENSITY, WORKABILITY, AND COMPRESSIVE STRENGTH OF CONCRETE

Dr. M. Adil Khan[*1], **Muhammad Naveed Khalil**[2], **Saad Hanif**[3], **Syed Zamin Raza Naqvi**[4]

[*1]*Resident Engineer, NESPAK*
[2]*National Centre of Excellence in Geology, University of Peshawar, Pakistan.*
[3]*Military College of Engineering Department of civil engineering National University of Sciences & Technology Risalpur*
[4]*COMSATS University Islamabad*

[*1]adee.uol@gmail.com, [2]geonaveed@uop.edu.pk, [3]saadhanif107@tamu.edu, [4]zrnaqvi.5@gmail.com

DOI: https://doi.org/10.5281/zenodo.18515305

Keywords
Waste pumice aggregate, lightweight concrete, workability, density, compressive strength, sustainable construction, coarse aggregate replacement.

Article History
Received: 08 December 2025
Accepted: 23 January 2026
Published: 07 February 2026

Corresponding Author: *
Dr. M. Adil Khan

Abstract
The increasing demand for sustainable and lightweight construction materials has led to growing interest in the utilization of industrial waste in concrete production. This study investigates the effect of waste pumice aggregate on the density, workability, and compressive strength of concrete. Waste pumice obtained from the apparel industry was used as a partial and full replacement for natural coarse aggregate at replacement levels of 0%, 20%, 40%, 60%, 80%, and 100%, while maintaining a constant water–cement ratio. The workability of fresh concrete was evaluated using slump tests, whereas hardened concrete was assessed in terms of dry density, self-weight, and compressive strength at curing ages of 7, 14, 21, and 28 days. The results indicate that increasing the waste pumice content leads to a progressive reduction in workability and compressive strength due to the porous structure and high water absorption capacity of pumice aggregate. However, a substantial reduction in concrete density and self-weight was achieved, confirming the effectiveness of waste pumice in producing lightweight concrete. Concrete mixes with low to moderate pumice replacement levels demonstrated acceptable strength performance suitable for lightweight and non-load bearing applications. The findings highlight the potential of waste pumice aggregate as an environmentally friendly alternative to natural coarse aggregate, contributing to sustainable construction and effective waste management.

1 Introduction

Concrete is the most widely used construction material in the world due to its versatility, durability, and availability of raw materials; however, its extensive use has led to serious environmental and structural challenges. Conventional concrete relies heavily on natural aggregates such as crushed stone and gravel, the continuous extraction of which results in depletion of natural resources, ecological imbalance, and increased environmental degradation. In addition, normal-weight concrete possesses high self-weight, which significantly contributes to dead loads in structures, leading to larger foundation requirements, higher reinforcement demand, and increased construction costs. These concerns have intensified the need for alternative materials and innovative approaches that can reduce concrete density while maintaining acceptable mechanical performance[1], [2].

Lightweight concrete has emerged as a practical solution to address these challenges by reducing self-weight without entirely compromising strength and serviceability. The reduction in density offers several structural and functional advantages, including lower dead loads, improved seismic performance, reduced transportation and handling costs, and enhanced thermal and acoustic insulation. Lightweight concrete is particularly attractive for non-load bearing elements, precast components, partition walls, façade panels, and low-rise buildings[3], [4], [5]. Despite these benefits, the application of lightweight concrete remains limited due to concerns related to reduced compressive strength, lower workability, and uncertainty regarding the performance of lightweight aggregates. The properties of lightweight concrete are largely governed by the characteristics of the aggregates used. Lightweight aggregates typically possess lower density and higher porosity than conventional aggregates, which directly affect workability, water demand, density, and strength development. Among various lightweight aggregates, pumice has attracted significant attention due to its natural availability and favorable physical properties. Pumice is a volcanic rock formed by the rapid cooling of gas-rich lava, resulting in a highly porous structure with low specific gravity. Its cellular nature makes it inherently lightweight and capable of reducing concrete density when used as an aggregate[6], [7].

In recent years, increasing focus has been placed on the utilization of industrial and agricultural waste materials in concrete production to promote sustainability and resource efficiency. One such waste material is pumice discarded by the apparel industry, where pumice stones are extensively used in stone-washing processes to achieve a desired texture and appearance in denim fabrics. After repeated use, these pumice stones lose their effectiveness and are disposed of as industrial waste. The disposal of waste pumice poses environmental concerns, including landfill occupation and potential pollution, while simultaneously representing a loss of a potentially valuable material[8], [9], [10], [11]. Utilizing waste pumice as a concrete aggregate provides an opportunity to address waste management issues and reduce the demand for natural aggregates. The incorporation of waste pumice aggregate into concrete has a direct influence on its fresh and hardened properties. Workability is one of the most critical fresh concrete properties affected by pumice aggregate due to its rough surface texture and high water absorption capacity. These characteristics tend to reduce slump and make concrete mixes stiffer, particularly at higher replacement levels. Understanding the effect of waste pumice on workability is essential for ensuring proper mixing, placement, and compaction of concrete in practical applications[9], [12], [13]. Density is another key parameter influenced by the use of waste pumice aggregate. Replacing conventional coarse aggregate with pumice significantly lowers the unit weight of concrete due to the low specific gravity and internal porosity of pumice particles. Reduced density not only decreases dead loads but also enhances thermal insulation performance, making pumice-based concrete suitable for energy-efficient construction. However, excessive reduction in density may adversely affect mechanical performance, highlighting the importance of identifying optimal replacement levels[9], [12], [13]. Compressive strength remains the most important mechanical property governing the applicability of concrete in construction. The use of waste pumice aggregate generally results in lower compressive strength compared to conventional concrete, primarily due to the weaker strength of pumice particles and the less dense interfacial transition zone between the aggregate and cement paste. The porous structure of pumice may act as a stress concentrator under compressive loading, leading to premature failure. Nevertheless, several studies have demonstrated that pumice-based concrete can still achieve sufficient compressive strength for non-load bearing and lightweight structural applications, particularly when replacement levels are carefully controlled[14], [15], [16], [17]. The relationship between density, workability, and compressive strength is complex and interdependent in lightweight concrete. A reduction in density is often accompanied by a decrease in compressive strength, while adjustments in water content to improve workability may further influence strength development. Therefore, a systematic investigation into the combined effect of waste pumice aggregate on these key properties is essential for establishing performance trends and practical guidelines for its use in concrete[18]. Evaluating concrete performance at multiple curing ages provides valuable insight into strength development behavior and hydration characteristics. Early-age strength is critical for construction scheduling and handling of precast elements, while later-age strength determines long-term performance. Assessing compressive strength at different ages allows for a comprehensive understanding of how waste pumice influences concrete behavior over time[19], [20], [21], [22]. The reuse of waste pumice aggregate in concrete aligns with sustainable construction principles by promoting recycling, reducing industrial waste, conserving natural resources, and lowering the environmental footprint of concrete production. In addition to environmental benefits, the use of waste pumice can provide economic advantages by reducing material costs and waste disposal expenses. However, for widespread adoption, it is necessary to clearly quantify its impact on workability, density, and compressive strength and to identify acceptable replacement ranges based on performance requirements.

A detailed investigation into the effect of waste pumice aggregate on density, workability, and compressive strength of concrete is therefore essential to determine its feasibility as an alternative coarse aggregate. Understanding these effects supports the development of lightweight, sustainable concrete materials that meet functional and mechanical requirements while contributing to environmentally responsible construction practices.

2 Methodology

2.1 Experimental Program Design

The experimental program was designed to evaluate the effect of waste pumice aggregate on the density, workability, and compressive strength of concrete. A laboratory-based experimental approach was adopted to ensure controlled conditions and repeatability of results. Conventional concrete was used as a reference, and several concrete mixes were prepared by partially and fully replacing natural coarse aggregate with waste pumice aggregate. The investigation focused on both fresh and hardened concrete properties, allowing a comprehensive assessment of material behavior. Replacement levels of waste pumice were selected to cover a wide range, enabling identification of performance trends and suitable replacement limits. The experimental design emphasized maintaining consistency in all variables other than the coarse aggregate type, ensuring that observed changes in concrete performance could be directly attributed to the inclusion of waste pumice.

2.2 Materials and Their Preparation

Ordinary Portland Cement was used as the binding material in all concrete mixes due to its widespread use in construction and compatibility with lightweight concrete production. Natural river sand served as the fine aggregate, while crushed stone was used as the natural coarse aggregate in the control mix. Waste pumice aggregate was collected from an apparel industry where pumice stones are discarded after repeated use in stone-washing operations. Prior to use, all aggregates were cleaned to remove dust, impurities, and loose particles. The waste pumice was air-dried and sieved to obtain particle sizes comparable to conventional coarse aggregate. Due to its high porosity and water absorption capacity, special attention was given to handling and preparation of pumice aggregate to ensure uniformity across concrete batches. All materials were tested to determine relevant physical properties required for accurate mix proportioning.

2.3 Concrete Mix Proportions and Mixing Procedure

Concrete mix proportions were developed in accordance with standard mix design guidelines. A control mix with 0% pumice replacement was prepared, along with mixes containing 20%, 40%, 60%, 80%, and 100% replacement of natural coarse aggregate by waste pumice on a weight basis. A constant water–cement ratio was maintained for all mixes to allow direct comparison of results. The cement content and fine aggregate content were kept constant throughout the experimental program. Concrete mixing was carried out using a laboratory concrete mixer. Dry materials were first mixed to achieve uniform distribution, followed by gradual addition of water. Mixing continued until a homogeneous and workable concrete mixture was obtained. Fresh concrete was immediately tested for workability to minimize the influence of time-dependent effects.

2.4 Specimen Casting, Curing, and Testing

Concrete specimens were cast in steel molds with dimensions of 150 mm × 150 mm × 150 mm for compressive strength testing. Each concrete mix consisted of multiple specimens to allow testing at different curing ages. After casting, the specimens were compacted properly to eliminate air voids and ensure uniform density. The molds were covered to prevent moisture loss and stored at room temperature for 24 hours. After demolding, the specimens were cured in water at a controlled temperature until the time of testing. Workability of fresh concrete was evaluated using the slump test, which provided an indication of consistency and ease of placement. Hardened concrete specimens were tested for dry density by measuring mass and volume prior to compressive strength testing. Compressive strength tests were conducted at curing ages of 7, 14, 21, and 28 days using a compression testing machine, with load applied at a constant rate until failure.

2.5 Data Collection and Analysis

Experimental data collected from workability, density, and compressive strength tests were systematically recorded and analysed. Slump values were compared across all mixes to assess the influence of waste pumice content on workability. Dry density results were analysed to quantify the reduction in unit weight relative to the control mix. Compressive strength results at different curing ages were evaluated to study strength development trends and the effect of pumice replacement level. Comparative analysis was performed between control and pumice-based concrete mixes to identify performance variations. Relationships between density and compressive strength were examined to establish correlations and assess the predictability of concrete behavior. The analysed results formed the basis for evaluating the suitability of waste pumice aggregate as a replacement material in lightweight concrete applications.

Figure 1 flowchart of methodology

Table 1 Detailed Methodology and Materials Description

Category	Material / Test	Description	Standard Followed	Purpose
Binding Material	Ordinary Portland Cement (OPC)	Commercially available OPC used as binder	ASTM C150	Provide strength and binding to concrete
Fine Aggregate	Natural River Sand	Clean, well-graded sand free from organic impurities	ASTM C33	Improve workability and packing
Coarse Aggregate (Control)	Crushed Stone	Locally sourced natural coarse aggregate	ASTM C33	Reference aggregate for comparison
Waste Aggregate	Waste Pumice	Collected from apparel industry stone-washing process	–	Lightweight coarse aggregate replacement
Cement Test	Fineness	Determined using sieve method	ASTM C786	Control hydration rate
Cement Test	Specific Gravity	Determined using Le Chatelier flask	ASTM C188	Mix proportion accuracy
Fine Aggregate Test	Water Absorption	SSD and oven-dry method	ASTM C128	Control effective water content
Fine Aggregate Test	Specific Gravity	Pycnometer method	ASTM C128	Mix design calculations

Fine Aggregate Test	Fineness Modulus	Sieve analysis	ASTM C136	Grading assessment
Coarse Aggregate Test	Water Absorption	SSD method	ASTM C127	Evaluate porosity
Coarse Aggregate Test	Bulk Density	Loose and compacted	ASTM C29	Density measurement
Pumice Aggregate Test	Water Absorption	High absorption evaluation	ASTM C127	Understand water demand
Pumice Aggregate Test	Bulk Density	Lightweight characterization	ASTM C29	Density reduction analysis
Mix Design	Mix Proportioning	0–100% pumice replacement	ACI 211.1	Produce consistent mixes
Fresh Concrete Test	Slump Test	Measurement of workability	ASTM C143	Evaluate consistency
Specimen Casting	Cube Specimens	150 × 150 × 150 mm cubes	ASTM C192	Strength testing
Curing	Water Curing	7, 14, 21, 28 days at 27±2°C	ASTM C511	Strength development
Hardened Concrete Test	Dry Density	Mass-to-volume ratio	ASTM C642	Weight reduction analysis
Strength Test	Compressive Strength	Universal testing machine	ASTM C39	Mechanical performance
Data Analysis	Correlation Study	Density vs strength	–	Performance evaluation

3 Results

3.1 Workability of Fresh Concrete

The workability of fresh concrete was assessed using slump tests for all mix proportions containing different percentages of waste pumice aggregate. The control mix exhibited the highest slump value, indicating good workability and ease of placement. As the percentage of waste pumice aggregate increased, a continuous reduction in slump was observed. Concrete mixes containing low pumice replacement levels showed moderate reduction in workability, while mixes with higher replacement levels exhibited significantly stiffer consistency. The reduction in slump values reflects the influence of the porous structure and high-water absorption capacity of pumice aggregate, which reduced the availability of free water in the concrete mix. Despite the reduction, all mixes maintained measurable slump values, indicating workable concrete suitable for laboratory casting.

Table 2: Slump Test Results

Mix ID	Pumice Replacement (%)	Slump (mm)
M0	0	75
M20	20	65
M40	40	55
M60	60	45
M80	80	35
M100	100	25

3.2 Density and Self-Weight of Hardened Concrete

The dry density of hardened concrete specimens decreased progressively with increasing waste pumice content. The control mix showed the highest density, typical of conventional concrete. Partial replacement of natural coarse aggregate with pumice resulted in noticeable reductions in density, while full replacement produced lightweight concrete with significantly lower unit weight. The reduction in density was consistent across all curing ages, indicating uniform distribution of pumice aggregate within the concrete matrix. The self-weight reduction achieved relative to the control mix increased with pumice replacement level, demonstrating the effectiveness of waste pumice in producing lightweight concrete.

Table 3: Dry Density and Self-Weight Reduction

Mix ID	Pumice (%)	Dry Density (kg/m³)	Self-Weight Reduction (%)
M0	0	2400	0
M20	20	2100	12.5
M40	40	1850	23.0
M60	60	1600	33.3
M80	80	1300	45.8
M100	100	950	60.4

3.3 Compressive Strength Results

3.3.1 Early-Age Compressive Strength (7 and 14 Days)

At early curing ages, the control mix achieved the highest compressive strength. Concrete mixes incorporating waste pumice exhibited lower strength values compared to the control, with strength reduction increasing as pumice content increased. At 7 days, mixes with low pumice replacement maintained relatively higher strength compared to mixes with high replacement levels. At 14 days, all mixes demonstrated strength gain, indicating continued hydration. However, the relative difference between control and pumice-based mixes remained evident.

Table 4: Early-Age Compressive Strength

Mix ID	Pumice (%)	7 Days (MPa)	14 Days (MPa)
M0	0	18.5	21.0
M20	20	16.8	19.2
M40	40	15.0	17.3
M60	60	12.8	15.0
M80	80	10.2	12.5
M100	100	8.0	10.1

3.3.2 Later-Age Compressive Strength (21 and 28 Days)

At later curing ages, compressive strength continued to increase for all mixes. The control mix achieved the highest strength at 28 days, while pumice-based mixes showed strength values proportional to their replacement level. Concrete with low to moderate pumice replacement achieved substantial strength gain, whereas mixes with high pumice content showed comparatively lower strength development.

Table 5: Later-Age Compressive Strength

Mix ID	Pumice (%)	21 Days (MPa)	28 Days (MPa)
M0	0	23.5	26.0
M20	20	21.2	23.5
M40	40	19.0	21.0
M60	60	16.5	18.2
M80	80	13.2	15.0
M100	100	11.0	12.8

3.3.3 Effect of Waste Pumice Replacement Level

The results indicate a systematic reduction in compressive strength with increasing pumice replacement level. Strength reduction at 28 days was relatively small for low replacement levels but became significant beyond moderate replacement. The percentage reduction in strength increased progressively as pumice content increased from 0% to 100%.

Table 6: Effect of Pumice Replacement on 28-Day Strength

Pumice Replacement (%)	28-Day Strength (MPa)	Strength Reduction (%)
0	26.0	0
20	23.5	9.6
40	21.0	19.2
60	18.2	30.0
80	15.0	42.3
100	12.8	50.8

3.3.4 Relationship Between Density and Compressive Strength

A strong relationship was observed between dry density and compressive strength of concrete. As density decreased with increasing pumice content, compressive strength also decreased. The results indicate a direct correlation between these two parameters, demonstrating that lighter concrete mixes generally exhibited lower strength values.

Table 7: Density–Strength Relationship

Mix ID	Dry Density (kg/m³)	28-Day Strength (MPa)
M0	2400	26.0
M20	2100	23.5
M40	1850	21.0
M60	1600	18.2
M80	1300	15.0
M100	950	12.8

3.4 Failure Characteristics of Concrete Specimens

During compressive strength testing, distinct failure patterns were observed. Control concrete specimens exhibited sudden brittle failure with vertical cracking and crushing. Pumice-based concrete specimens showed more distributed cracking and gradual failure, particularly at higher replacement levels. Crushing of pumice particles was observed in specimens with high pumice content, indicating aggregate-controlled failure behavior.

4 Discussion

The results obtained from this experimental investigation clearly demonstrate the significant influence of waste pumice aggregate on the fresh and hardened properties of concrete. The progressive reduction in workability observed with increasing pumice content is primarily linked to the inherent physical characteristics of pumice aggregate. Its highly porous structure and rough surface texture lead to increased water absorption during mixing, which reduces the amount of free water available for lubrication within the concrete matrix. Consequently, concrete mixes containing higher proportions of pumice exhibited lower slump values and stiffer consistency. This behavior indicates that, although waste pumice can be effectively used as a coarse aggregate replacement, careful control of water content or preconditioning of the aggregate is necessary to maintain adequate workability, particularly at higher replacement levels[23], [24], [25], [26], [27], [28], [29].

The reduction in dry density observed across all pumice-based concrete mixes confirms the effectiveness of waste pumice as a lightweight aggregate. The low specific gravity of pumice particles significantly contributes to lowering the unit weight of concrete, resulting in substantial self-weight reduction compared to conventional concrete. This characteristic is especially advantageous for applications where minimizing dead load is critical, such as precast concrete elements, partition walls, and non-load bearing structural components. The consistent decrease in density with increasing pumice content also suggests that waste pumice can be used to produce concrete with predictable weight characteristics, which is essential for design and construction planning[30], [31], [32], [33], [34], [35].

Compressive strength results reveal a clear dependency on the level of waste pumice replacement. At early curing ages, pumice-based concrete exhibited lower strength than the control mix, although all mixes showed continuous strength development over time. The reduction in early-age strength can be attributed to the relatively weaker mechanical properties of pumice particles and the presence of larger internal voids within the aggregate. Additionally, the interfacial transition zone between pumice aggregate and cement paste is generally less dense than that formed with conventional aggregates, leading to reduced load transfer efficiency under compressive loading. Despite this, the steady increase in strength between 7 and 14 days indicates that hydration processes were not significantly impeded by the inclusion of pumice aggregate.

At later curing ages, the strength development trends remained consistent, with pumice-based concrete continuing to gain strength, albeit at lower levels than conventional concrete. Concrete mixes containing low to moderate pumice replacement levels demonstrated compressive strength values that remain suitable for lightweight and non-load bearing applications. The results suggest that replacement levels in the range of approximately 20% to 60% provide a favorable balance between weight reduction and strength retention. Beyond this range, the loss in compressive strength becomes more pronounced, limiting the structural applicability of high pumice-content mixes. These findings emphasize the importance of optimizing replacement levels based on specific performance requirements[1], [4], [36].

The relationship between dry density and compressive strength observed in this study highlights a fundamental characteristic of lightweight concrete. As density decreases due to increased pumice content, compressive strength also decreases in a nearly proportional manner. This strong correlation indicates that density can serve as a reliable indicator of expected strength in pumice-based concrete. Such a relationship is particularly useful for preliminary design and quality control purposes, allowing engineers to estimate strength based on density measurements. The predictable nature of this relationship further supports the feasibility of incorporating waste pumice into concrete mix design for targeted applications.

Failure characteristics observed during compressive strength testing provide additional insight into the mechanical behavior of pumice-based concrete. Control specimens exhibited typical brittle failure with sudden cracking and crushing, reflecting the behavior of conventional concrete. In contrast, concrete containing waste pumice showed more distributed cracking and gradual failure, especially at higher replacement levels. The crushing of pumice particles rather than sudden fracture of the cement matrix indicates that aggregate strength governs the failure mechanism in these mixes. This behavior suggests increased energy absorption and reduced brittleness, which may be beneficial in certain structural applications where ductility is desired.

The combined effects of reduced workability, lower density, and decreased compressive strength highlight the trade-offs involved in using waste pumice aggregate in concrete. While higher pumice content significantly enhances lightweight characteristics, it also introduces challenges related to workability and strength reduction. These challenges can potentially be mitigated through improved mix design strategies, such as aggregate pre-saturation, optimized grading, or the use of chemical admixtures. The results of this study indicate that with appropriate adjustments, waste pumice aggregate can be effectively utilized without severely compromising concrete performance[15], [16], [17].

From a sustainability perspective, the reuse of waste pumice aggregate offers considerable environmental benefits. Diverting pumice waste from landfills reduces environmental pollution and disposal costs, while decreasing the demand for natural coarse aggregates conserves natural resources. The successful incorporation of waste pumice into concrete supports sustainable construction practices and aligns with the principles of circular economy. Additionally, the potential cost savings associated with reduced material consumption and waste management further enhance the practical viability of pumice-based lightweight concrete.

5 Conclusion and Recommendation

The experimental investigation demonstrated that waste pumice aggregate can be effectively utilized as a partial or full replacement for natural coarse aggregate in concrete, resulting in significant reductions in density and self-weight. The results confirmed that increasing the pumice replacement level consistently decreases the unit weight of concrete due to the low specific gravity and high porosity of pumice particles. This reduction in self-weight offers clear advantages for applications where dead load minimization is critical, such as non-load bearing structural elements, precast components, and lightweight construction systems. The study verified that waste pumice has strong potential as a lightweight aggregate capable of producing concrete with predictable density characteristics.

The workability of fresh concrete was found to decrease progressively with increasing waste pumice content. This behavior is primarily attributed to the high water absorption capacity and rough surface texture of pumice aggregate, which reduces the availability of free water in the mix. Although all mixes remained workable, higher replacement levels resulted in stiffer concrete, indicating the need for careful water control or aggregate preconditioning. These findings highlight the importance of mix design optimization when incorporating waste pumice to ensure proper handling, placement, and compaction in practical construction scenarios.

Compressive strength results showed a clear reduction with increasing pumice replacement levels. However, all concrete mixes exhibited continuous strength development with curing age, demonstrating that the inclusion of waste pumice does not hinder cement hydration. Concrete mixes containing low to moderate pumice replacement levels achieved compressive strength values suitable for lightweight and non-load bearing applications. Replacement levels beyond this range resulted in significant strength loss, limiting their applicability to situations with minimal structural demand. The observed strong correlation between dry density and compressive strength indicates that density can be used as a reliable indicator for predicting the mechanical performance of pumice-based concrete.

The failure characteristics of pumice-based concrete differed from those of conventional concrete, with more distributed cracking and gradual failure observed at higher pumice contents. This behavior suggests reduced brittleness and improved energy absorption, which may be advantageous in specific applications. Overall, the results demonstrate that waste pumice aggregate can be successfully incorporated into concrete, provided that its limitations are properly addressed through appropriate mix design and quality control measures.

Based on the findings of this study, it is recommended that waste pumice aggregate be used primarily at low to moderate replacement levels to achieve an optimal balance between strength retention and weight reduction. Preconditioning or partial saturation of pumice aggregates is strongly recommended to minimize excessive water absorption and improve workability. The use of chemical admixtures should also be considered to enhance fresh and hardened concrete properties, particularly at higher pumice contents. Further research is recommended to investigate durability-related properties, long-term performance, and microstructural behavior of pumice-based concrete. Additionally, field-scale studies and life-cycle assessments would provide valuable insight into the practical and environmental benefits of using waste pumice aggregate in sustainable construction practices.

REFERENCES

W. Ahmad, A. Ahmad, K. Ostrowski, F. Aslam, and P. Joyklad, "A scientometric review of waste material utilization in concrete for sustainable construction," Case Stud. Constr. Mater., Dec. 2021, doi: 10.1016/j.cscm.2021.e00683.

M. Ali, A. Kumar, A. Yvaz, and B. Salah, "Central composite design application in the optimization of the effect of pumice stone on lightweight concrete properties using RSM," Case Stud. Constr. Mater., Feb. 2023, doi: 10.1016/j.cscm.2023.e01958.

A. Alqarni, "A comprehensive review on properties of sustainable concrete using volcanic pumice powder ash as a supplementary cementitious material," Constr. Build. Mater., Mar. 2022, doi: 10.1016/j.conbuildmat.2022.126533.

C. Amel, E. Kadri, Y. Sebaibi, and H. Soualhi, "Dune sand and pumice impact on mechanical and thermal lightweight concrete properties," Constr. Build. Mater., vol. 133, pp. 209–218, Feb. 2017, doi: 10.1016/j.conbuildmat.2016.12.043.

C. Andrea and Nicolò, "LIGHTWEIGHT CONCRETE USING LOCAL NATURAL LIGHTWEIGHT AGGREGATE," vol. 7, pp. 490–497, Mar. 2020, doi: 10.31838/jcr.07.04.93.

X. Chen, X. Li, and X. Song, "Structural Design and Performance Optimization of Green Concrete Based on Recycled Pumice and Modified Rubber Powder," Appl. Sci., Apr. 2024, doi: 10.3390/app14083372.

A. A. J. Ghanim, F. U. Rahman, W. Adil, A. Zeyad, and H. Magbool, "Experimental Investigation of Industrial wastes in concrete: Mechanical and microstructural evaluation of Pumice Powder and Fly Ash in concrete," Case Stud. Constr. Mater., Mar. 2023, doi: 10.1016/j.cscm.2023.e01999.

K. Hossain, S. Ahmed, and M. Lachemi, "Lightweight concrete incorporating pumice based blended cement and aggregate: Mechanical and durability characteristics," Constr. Build. Mater., vol. 25, pp. 1186–1195, Mar. 2011, doi: 10.1016/j.conbuildmat.2010.09.036.

R. Kumar, A. Srivastava, and R. Lakhani, "Industrial Wastes-Cum-Strength Enhancing Additives Incorporated Lightweight Aggregate Concrete (LWAC) for Energy Efficient Building: A Comprehensive Review," Sustainability, Dec. 2021, doi: 10.3390/su14010331.

M. Jayadurgalakshmi and S. Kandasamy, "Behaviour of cenosphere and pumice powder as partial cement substitute material in the sustainable production of concrete," J. Build. Pathol. Rehabil., vol. 9, Mar. 2024, doi: 10.1007/s41024-024-00397-4.

R. Karthika, V. Vidyapriya, K. Sri, K. Beaula, R. Harini, and M. Sriram, "Experimental study on lightweight concrete using pumice aggregate," Mater. Today Proc., Jan. 2021, doi: 10.1016/j.matpr.2020.09.762.

W. Luo, Z. Shi, W. Wang, A. Yu, and Z. Liu, "Eco-Friendly Cement Clinker Manufacturing Using Industrial Solid Waste and Natural Idle Resources as Alternative Raw Materials," Energy Environ. Manag., May 2025, doi: 10.63333/eem.v1n27.

Muhtar, "Performance-based experimental study into quality zones of lightweight concrete using pumice aggregates," Case Stud. Constr. Mater., Feb. 2023, doi: 10.1016/j.cscm.2023.e01960.

D. Oyejobi, A. Firoozi, D. B. Fernández, and S. Avudaiappan, "Integrating Circular Economy Principles into Concrete Technology: Enhancing Sustainability Through Industrial Waste Utilization," Results Eng., Sep. 2024, doi: 10.1016/j.rineng.2024.102846.

D. A. Rasool, H. Al-Moameri, and M. Abdulkarem, "REVIEW OF RECYCLING NATURAL AND INDUSTRIAL MATERIALS EMPLOYMENTS IN CONCRETE," J. Eng. Sustain. Dev., Mar. 2023, doi: 10.31272/jeasd.27.2.3.

M. Y. Reddy, V. K. V. Rao, and S. Reddy, "A Study on Mechanical and Durability Properties of Structural Concrete using Pumice and Sintered fly ash Aggregates," IOP Conf. Ser. Mater. Sci. Eng., vol. 1132, 2021, doi: 10.1088/1757-899x/1132/1/012002.

M. Shafiq et al., "Evaluation of Mechanical Properties of Lightweight Concrete with Pumice Aggregate," Adv. Sci. Technol. Res. J., Jun. 2021, doi: 10.12913/22998624/135198.

M. Tuncer, A. Bideci, B. Çomak, G. Durmuş, and Ö. S. Bideci, "Experimental Investigation of Durability Properties of Polymer Coated Pumice Aggregate Lightweight Concretes," Polymers, vol. 17, Jan. 2025, doi: 10.3390/polym17020253.

G. Gali, A. Khan, S. khan, S. khalil, Q. Shah, and M. Khan, "Experimental Study on the Effects of Freeze-Thaw Progressions and Performance of Soil with Non-Toxic Bio-Enzyme," J. ICT Des. Eng. Technol. Sci., vol. 7, no. 1, pp. 12–20, Jun. 2023, doi: 10.33150/JITDETS-7.1.3.

W. Khan et al., "Transforming Expansive Clays FROM Waste TO Value: Dual Ash Stabilization Strategy FOR Augmenting Black Cotton Subgrade Soil Performance," vol. 11, pp. 5065–5073, Oct. 2025, doi: 10.64252/cz07k049.

S. Nawaz et al., "Flexural Performance Evaluation Of Glass Fiber Reinforced Polymer Bars (GFRP) In Doubly Reinforced Beams: An Experimental Approach," Oct. 2025.

Q. Shah, K. Byemba, G. Gali, A. Muhammad, A. Khan, and M. Khan, "To Stabilize Shear Strength Properties of an Unwanted Subgrade Soil Utilizing Rock Dust," J. ICT Des. Eng. Technol. Sci., vol. 7, no. 2, pp. 1–6, Dec. 2023, doi: 10.33150/JITDETS-7.2.1.

M. Ahmad et al., "Supervised Learning Methods for Modeling Concrete Compressive Strength Prediction at High Temperature," Materials, vol. 14, Apr. 2021, doi: 10.3390/ma14081983.

A. Ahmad et al., "Prediction of Geopolymer Concrete Compressive Strength Using Novel Machine Learning Algorithms," Polymers, vol. 13, Oct. 2021, doi: 10.3390/polym13193389.

B. Alibrahim, A. Habib, and M. Habib, "Developing a brain inspired multilobar neural networks architecture for rapidly and accurately estimating concrete compressive strength," Sci. Rep., vol. 15, Jan. 2025, doi: 10.1038/s41598-024-84325-z.

P. Asteris and V. Mokos, "Concrete compressive strength using artificial neural networks," Neural Comput. Appl., vol. 32, pp. 11807–11826, Dec. 2019, doi: 10.1007/s00521-019-04663-2.

I. Ekanayake, D. Meddage, and U. Rathnayake, "A novel approach to explain the black-box nature of machine learning in compressive strength predictions of concrete using Shapley additive explanations (SHAP)," Case Stud. Constr. Mater., Jun. 2022, doi: 10.1016/j.cscm.2022.e01059.

M. Bypour, M. Yekrangnia, and M. Kioumarsi, "Machine Learning-Driven Optimization for Predicting Compressive Strength in Fly Ash Geopolymer Concrete," Clean. Eng. Technol., Jan. 2025, doi: 10.1016/j.clet.2025.100899.

P. Asteris, A. Skentou, A. Bardhan, P. Samui, and K. Pilakoutas, "Predicting concrete compressive strength using hybrid ensembling of surrogate machine learning models," Cem. Concr. Res., Jul. 2021, doi: 10.1016/j.cemconres.2021.106449.

M. Elshaarawy, M. Alsaadawi, and A. Hamed, "Machine learning and interactive GUI for concrete compressive strength prediction," Sci. Rep., vol. 14, Jul. 2024, doi: 10.1038/s41598-024-66957-3.

D. Feng et al., "Machine learning-based compressive strength prediction for concrete: An adaptive boosting approach," Constr. Build. Mater., Jan. 2020, doi: 10.1016/j.conbuildmat.2019.117000.

Y.-M. Hong, "Performance Comparison of Machine Learning Models for Concrete Compressive Strength Prediction," Materials, vol. 17, Apr. 2024, doi: 10.3390/ma17092075.

A. Q. Khan, H. A. Awan, M. Rasul, Z. A. Siddiqi, and A. Pimanmas, "Optimized Artificial Neural Network Model for Accurate Prediction of Compressive Strength of Normal and High Strength Concrete," Clean. Mater., Nov. 2023, doi: 10.1016/j.clema.2023.100211.

H. Nguyen, T. Vu, T. Vo, and H. Thai, "Efficient machine learning models for prediction of concrete strengths," Constr. Build. Mater., Jan. 2021, doi: 10.1016/j.conbuildmat.2020.120950.

P. Li, Z. Zhang, and J. Gu, "Prediction of Concrete Compressive Strength Based on ISSA-BPNN-AdaBoost," Materials, vol. 17, Nov. 2024, doi: 10.3390/ma17235727.

A. Capeto, M. Jesus, B. Uribe, A. S. Guimarães, and A. Oliveira, "Building a Greener Future: Advancing Concrete Production Sustainability and the Thermal Properties of 3D-Printed Mortars," Buildings, May 2024, doi: 10.3390/buildings14051323.