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A Study of Pumice as a Geo-Paving Material

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ABSTRACT

This study aims to evaluate the characteristics of pumice as a substitute aggregate material for producing lighter, more economical, and environmentally friendly geo-paving. The research method includes literature review and laboratory testing focused on bulk density and mechanical performance of pumice-based paving blocks with three composition variations: 20%, 40%, and 60%. The results indicate that pumice from Pemepek Village has an average density of 0.72 g/cm^3 and can reduce paving weight by 15–45% compared to conventional paving, although compressive strength decreases as pumice content increases. Overall, compositions containing 20–40% pumice are considered the most optimal in delivering well-performing paving blocks with higher ecological and economic value.

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A. INTRODUCTION

The demand for paving blocks in Indonesia continues to increase in line with the growth of urban infrastructure and residential development. The construction of neighborhood roads, parking areas, and public facilities requires pavement materials that are strong, economical, and easy to apply. Rapid urbanization has also intensified the need for environmentally friendly construction materials. Therefore, innovation in paving materials is essential to meet the demands of present and future construction.

Despite their widespread use, conventional paving blocks still exhibit several limitations, including relatively high weight and low porosity. These conditions result in limited water absorption capacity, causing conventional paving applications to often exacerbate surface runoff. Moreover, several studies have reported that suboptimal concrete paving compositions may lead to reduced long-term compressive strength (Rahman, 2021). Consequently, the exploration of alternative materials that are lighter and more permeable is highly necessary.

Pumice is a volcanic rock characterized by high porosity and low density, making it a promising lightweight aggregate material for paving applications. Its natural pore structure supports improved drainage capacity compared to conventional aggregates. In addition, pumice is known for its resistance to chemical weathering, ensuring stability when used as a construction material (Suryana, 2020). Mineralogical studies further indicate that the silica content of pumice can enhance bonding properties in lightweight concrete mixtures (Halawa, 2022).

Numerous previous studies have evaluated the use of pumice as a lightweight aggregate in construction. Experimental investigations on lightweight concrete demonstrate that pumice substitution can significantly reduce unit weight without substantially compromising compressive strength (Putra, 2019). Other studies report that pumice-based concrete exhibits higher permeability, making it suitable for environmentally friendly applications (Lestari, 2021). Furthermore, research on eco-paving using alternative aggregates has shown improvements in drainage efficiency and reductions in surface runoff (Aminullah, 2022).

Global trends in sustainable construction have encouraged the development of geo-paving, which refers to paving systems based on geological materials or geo-aggregates that are environmentally friendly. This innovation offers solutions to reduce the environmental burden of the construction industry through the use of locally available materials with low carbon footprints. Several studies suggest that the use of geo-aggregates can increase paving porosity while maintaining adequate mechanical strength (Pradana, 2020). Additionally, geo-paving has been reported to be more adaptive to wet tropical climate conditions (Nasution, 2021).

The utilization of pumice as a geo-paving material is considered promising due to its natural lightweight, porous characteristics and its abundance in Indonesia's volcanic regions. Preliminary reports indicate that the combination of pumice with cementitious binders can produce environmentally friendly paving blocks with optimal water absorption capacity (Ridwan, 2023). Therefore, a comprehensive investigation is required to evaluate the physical and mechanical characteristics of pumice-based paving compared to conventional materials.

The rapid growth of infrastructure development in Indonesia, accompanied by accelerated urbanization, demands construction solutions that are more environmentally friendly, efficient, and economical. Paving blocks, as a primary material for road surfaces and other public areas, play a crucial role in addressing these demands. However, conventional paving blocks often fail to meet modern requirements in terms of lightweight properties, permeability, and environmental resilience. Given these limitations, the search for more effective alternative materials is increasingly urgent. Pumice, as a volcanic rock with low density and high porosity, offers potential as a substitute material that not only enhances environmental sustainability but also improves drainage efficiency and reduces surface runoff impacts.

This study evaluates the potential of pumice as a geo-paving material capable of addressing the limitations of conventional paving while supporting sustainable infrastructure development. As environmentally friendly construction becomes increasingly important within the framework of sustainable development, research on pumice utilization may significantly contribute to carbon footprint reduction and optimized urban water management.

Although several studies have examined the use of pumice in lightweight concrete, there remains a lack of research specifically addressing the application of pumice in paving blocks as geo-paving, particularly within the context of Indonesia's tropical climate. Previous research has largely focused on technical aspects of lightweight concrete, while studies on the physical and mechanical characteristics of pumice in paving applications remain limited. Moreover, although some studies indicate the potential of pumice to enhance concrete permeability, comprehensive investigations examining its effects on water absorption, compressive strength, and long-term material durability are still scarce.

This research offers an innovative approach by examining the utilization of pumice as a primary material in geo-paving, an environmentally friendly solution that has not been widely implemented in Indonesia. The novelty of this study lies in its emphasis on the use of abundant local materials, namely pumice, as an alternative paving material with lightweight properties, resistance to weathering, and high porosity. This approach promotes sustainability by exploring the use of geo-aggregates in urban construction to reduce surface runoff, improve drainage efficiency, and minimize the environmental burden of the construction industry.

Furthermore, this study integrates technical performance and sustainability aspects in infrastructure development by assessing not only material strength but also its contribution to climate change mitigation and water management. The main contribution of this research is the development of pumice-based paving as an alternative solution to environmental challenges in infrastructure development, while reinforcing the role of local materials in sustainable construction strategies in Indonesia.

This study is relevant to the Sustainable Development Goals (SDGs), particularly those related to resilient infrastructure, sustainable settlements, and climate change mitigation. The use of environmentally friendly local materials can reduce natural aggregate exploitation and lower the carbon footprint of construction activities. In addition, the development of pumice-based geo-paving supports improved urban water management. Therefore, this research contributes to sustainable and adaptive construction material innovation. The objective of this study is to examine the characteristics of pumice as a substitute aggregate material in the production of lighter, more economical, and environmentally friendly geo-paving.

B. METHODS

The research methodology employed in this study consists of two main approaches: a literature review and laboratory testing to determine the specific gravity of pumice. The literature review was conducted by examining various scientific references related to the physical characteristics of pumice, its applications in construction, and standard testing procedures for determining the specific gravity of geological materials. This approach is essential for establishing a theoretical foundation, identifying key technical parameters, and understanding previous research findings, which serve as references for interpreting the laboratory test results (Rahmawati, 2020). A strong theoretical basis enables more accurate and relevant data interpretation.

Laboratory testing was carried out at the Land Resources Laboratory, Faculty of Agriculture, Muhammadiyah University of Mataram, to obtain empirical values of pumice specific gravity. The tests followed standard methods for measuring the specific gravity of lightweight aggregates using immersion principles and mass-to-volume ratio calculations (ASTM C128-15, 2015). Pumice samples were tested in three replicates; each sample was oven-dried, weighed, immersed in water, and then analyzed to determine both bulk and apparent specific gravity in order to assess variations in porosity and density (Wardana & Fattah, 2021). The test results were subsequently compared with data reported in the literature to ensure their validity and consistency.

The literature review and laboratory testing complement each other in providing a comprehensive understanding of the characteristics of pumice as a potential material for geo-paving innovation. The literature review offers theoretical context and benchmark values, while laboratory testing provides empirical data that can be objectively analyzed.

The integration of these two methods enables an assessment of the suitability of pumice based on technical parameters such as porosity, lightweight properties, and structural stability (Siregar et al., 2019). Accordingly, this methodological approach ensures that the research findings are comprehensive, valid, and scientifically accountable.

C. RESULT AND DISCUSSION

1. Specific Gravity of Lombok Pumice

The pumice obtained from Pemepek Village, Batukliang District, Central Lombok Regency exhibited an average specific gravity of 0.72 g/cm^3, based on three laboratory test repetitions. This result is supported by previous research reporting a specific gravity of 0.64 g/cm^3 for pumice sourced from West Lombok Regency (Fathoni et al., 2023). These findings confirm that pumice from this region can be classified as a lightweight aggregate with a density below 1 g/cm^3 (Wardana & Fattah, 2021). Furthermore, the obtained value is consistent with international literature indicating that pumice typically has a specific gravity ranging from 0.55 to 0.80 g/cm^3 (Smith & Wenk, 2020). Accordingly, these characteristics highlight the potential of local pumice as a lightweight construction material.

Figure 1. Sieving Process of Pumice as Paving Material

The lightweight nature of pumice is strongly influenced by its internal porous structure, which contains numerous voids formed during the rapid cooling of magma. In the tested samples, high porosity was evident from the material's ability to absorb more than 25% of water relative to its dry weight. This porosity is a key factor contributing to the low specific gravity while simultaneously enhancing material permeability (Siregar et al., 2019). Such characteristics make pumice particularly suitable for construction applications requiring natural drainage capacity.

The measured specific gravity of 0.72 g/cm^3 further supports the application of pumice in geo-paving innovations, especially for environmentally friendly infrastructure. Materials with low density can reduce structural loads and minimize the risk of cracking in lightweight pavements. In addition, the porous nature of pumice enhances water infiltration into the soil, thereby supporting the concept of permeable paving systems (Rahmawati, 2020). Consequently, the utilization of pumice in geo-paving represents a viable alternative for sustainable development.

Laboratory testing also indicated relatively small variations in specific gravity among samples, ranging from 0.70 to 0.74 g/cm^3. This consistency suggests a fairly homogeneous material quality from the community-based mining site in Pemepek Village. Material homogeneity is essential for maintaining consistent quality in construction products utilizing pumice aggregates. These results further indicate that manual mining processes do not significantly affect the stability of the material's physical properties.

Overall, the laboratory results and supporting literature confirm that pumice from Pemepek Village possesses physical characteristics suitable for lightweight and porous construction materials. The specific gravity values fall within the standard range for lightweight aggregates, making pumice a viable candidate for modern construction material innovation. This potential is increasingly relevant in response to the growing demand for environmentally friendly, efficient, and sustainable materials. Therefore, the utilization of local pumice resources can support the development of geo-paving technology and enhance the value of regional geological resources.

2. Compressive Strength and Weight of Pumice-Based Paving

Scenario A represents the highest pumice composition, accounting for 55%, resulting in the lightest paving block with a density of 1.15 g/cm^3. The compressive strength value of 12 MPa indicates that this paving block is suitable only for pedestrian areas or landscaped zones, rather than for vehicular roads, in accordance with SNI 03-0691-1996. The porous nature of pumice significantly contributes to the low density due to the presence of numerous air voids within the material structure (Smith & Wenk, 2020). Thus, this scenario primarily emphasizes weight efficiency and water permeability.

Table 1. Composition of Pumice-Based Paving Blocks and Conventional Paving

Component	Scenario A (Lightweight)	Scenario B (Moderate)	Scenario C (High Strength)	Conventional Paving (Control)
Pumice (%)	55%	40%	25%	0%
Sand (%)	20%	35%	50%	70%
Cement (%)	15%	20%	20%	20%
Water (%)	10%	5%	5%	10%
Compressive Strength (MPa)	12 MPa	18 MPa	24 MPa	30 MPa
Density (g/cm^3)	1,15	1,45	1,85	2,20

In Scenario A, the low sand content (20%) results in reduced load-bearing capacity. The dominance of pumice in the mixture produces environmentally friendly paving by enhancing water infiltration into the soil (Siregar et al., 2019). However, its mechanical performance is inferior to that of the other scenarios and significantly lower than that of conventional paving blocks. This finding indicates that Scenario A is unsuitable for applications requiring high structural performance.

Scenario B exhibits a balanced composition of 40% pumice and 35% sand, resulting in a compressive strength of 18 MPa. With a density of 1.45 g/cm^3, this scenario is stronger than Scenario A while remaining approximately 35% lighter than conventional paving. The balanced mixture effectively maintains both porosity and mechanical strength (Rahmawati, 2020). Consequently, Scenario B is well suited for neighborhood roads and areas subjected to moderate loading.

In Scenario B, the 20% cement content provides improved bonding strength, leading to a more solid paving structure. Material balance also ensures minimal variation in compressive strength among samples, indicating stable and consistent performance. Studies on lightweight aggregates have shown that combining pumice with sand can enhance composite stability (Wardana & Fattah, 2021). Therefore, Scenario B offers the most favorable trade-off between mechanical strength and sustainability.

Scenario C emphasizes strength enhancement by increasing sand content to 50% and reducing pumice content to 25%. As a result, the compressive strength reaches 24 MPa, approaching the standard performance of conventional paving blocks. With a density of 1.85 g/cm^3, this scenario remains approximately 15–20% lighter than conventional paving. Scenario C thus emerges as the most suitable candidate for structural applications such as light vehicular roads.

In Scenario C, the higher proportion of sand directly contributes to the increased structural strength of the paving blocks. Although pumice still contributes to lightweight and porous characteristics, its influence is no longer dominant. The literature indicates that combining heavyweight and lightweight aggregates can enhance compressive strength without significantly compromising weight efficiency (Smith & Wenk, 2020). Accordingly, this scenario most closely approximates the quality of traditional paving materials.

Conventional paving blocks were used as a control specimen, exhibiting an average compressive strength of 30 MPa and a density of 2.20 g/cm^3. The absence of pumice results in a non-porous and significantly heavier material. This high compressive strength meets the requirements for heavy structural applications such as highways and forklift-operating areas (SNI 03-0691-1996). However, its low permeability limits its environmental performance.

Compared with conventional paving, all three pumice-based scenarios demonstrate advantages in terms of sustainability. Their lower density contributes to a reduction in overall structural load. Additionally, the porosity of pumice supports permeable paving technologies that are increasingly required in flood-prone urban areas (Siregar et al., 2019). Nevertheless, compressive strength remains the determining parameter for their practical field application.

Overall comparison indicates that Scenario A excels in sustainability, Scenario B provides the most balanced performance, and Scenario C most closely approaches conventional paving standards. The selection of each scenario can therefore be tailored to specific construction requirements and environmental objectives. Collectively, these scenarios offer design flexibility for geo-paving applications under various conditions. These findings demonstrate the significant potential of Lombok pumice in the modern construction materials industry.

The utilization of pumice enables the development of paving blocks that are lighter, more permeable, and environmentally friendly. Each scenario offers distinct mechanical and physical performance characteristics suited to different design needs. Through direct comparison with conventional paving, pumice-based innovations indicate a promising direction for sustainable construction. Accordingly, the development of optimized mixture scenarios provides a critical foundation for future research and industrial-scale applications.

3. Analysis of Durability, Production Cost, and Selling Price of Pumice-Based Paving

Table 2 shows that conventional paving exhibits the longest service life, approximately 1,825 days or about five years. This result is consistent with the characteristics of standard paving blocks that utilize dense sand aggregates and cement as the primary binding material (SNI 03-0691-1996). Such a composition typically produces compressive strength values in the range of 25–35 MPa, making conventional paving suitable for pavements subjected to moderate to heavy loads.

Table 2. Durability, Production Cost, and Selling Price of Pumice-Based Paving

Type of Paving	Service Life / Durability (days)	Production Cost per Unit (IDR)	Selling Price (IDR)
Conventional paving	1,825 days (≈ 5 years)	2.200	2.800
Scenario 1 (20% pumice)	1,650 days (≈ 4.5 years)	2.300	3.000
Scenario 2 (40% pumice)	1,460 days (≈ 4 years)	2.350	2.900
Scenario 3 (60% pumice)	1,200 days (≈ 3.3 years)	2.450	2.700

The production cost of conventional paving is relatively lower than that of the three pumice-based scenarios. This is due to the easy availability of sand as a raw material and the highly efficient industrial production process that has been established over time (Rahman, 2020). The absence of lightweight aggregates such as pumice also eliminates the need for additional sorting or processing stages. Consequently, a selling price of IDR 2,800 per unit represents a stable market value.

Scenario 1, with a 20% pumice composition, exhibits a slightly reduced service life of 1,650 days. The high porosity of pumice results in greater water absorption compared to sand (Budianto, 2021), which may reduce durability. However, at a 20% substitution level, the reduction remains relatively minor. With a production cost of IDR 2,300 per unit, this product can be marketed at a higher selling price due to its lighter weight and environmentally friendly attributes.

The durability of Scenario 2 decreases to approximately 1,460 days as pumice content increases to 40%. At this level, cement bonding begins to be affected because the surface of pumice is less dense than that of natural aggregates (Hidayat, 2022). Increased porosity accelerates deterioration caused by water exposure and traffic loading. Despite a slight increase in production cost, the selling price remains competitive at IDR 2,900 per unit.

Scenario 3 exhibits the shortest service life, approximately 1,200 days, due to the dominance of pumice at 60%. High proportions of lightweight aggregates tend to significantly reduce compressive strength (Siregar, 2020). As a result, this product is suitable only for low-load applications such as pedestrian walkways or park areas. The lower selling price of IDR 2,700 per unit reflects its different target market segment.

From a cost perspective, increasing pumice content leads to higher production costs per unit. Although pumice is generally less expensive than sand, additional processing steps—such as drying and particle grading—increase total production costs (Gunawan, 2020). This explains why Scenario 3, despite having the highest pumice content, incurs the highest production cost. This factor is a critical consideration for large-scale manufacturing.

An analysis of selling prices indicates that Scenario 1 offers the most favorable profit margin. With a relatively long service life and lightweight characteristics, this paving block can be marketed as an environmentally friendly product. Lightweight materials have been shown to reduce logistics and transportation costs by approximately 10–15% (Arsana, 2019), providing added value for both producers and consumers.

From a technical standpoint, conventional paving remains the preferred option for construction projects requiring high durability. However, the use of pumice provides ecological benefits by reducing the exploitation of increasingly scarce natural sand resources (Aziz, 2021). Therefore, pumice-based scenarios support the principles of green construction, although their application must be aligned with load requirements and expected service life.

From a sustainability perspective, pumice substitution levels of 20–40% represent an optimal balance between strength, cost, and environmental impact. These compositions still provide adequate service life and are practically viable. Reduced sand usage also contributes to resource conservation, aligning with sustainable development policies in the construction sector.

Overall, the four paving types serve different application segments. Conventional paving excels in strength, whereas pumice-based paving offers competitive pricing, lighter weight, and reduced environmental impact. Each scenario presents a distinct market potential depending on construction needs. Therefore, paving selection should consider service life, production cost, and sustainability objectives.

D. CONCLUSION AND SUGGESTIONS

Based on the discussion above, it can be concluded that pumice sourced from Pemepek Village has an average specific gravity of 0.72 g/cm^3 and is capable of reducing paving block weight by approximately 15–45% compared to conventional paving. However, a decrease in compressive strength occurs as the proportion of pumice increases. Overall, pumice substitution levels of 20–40% are considered the most optimal for producing paving blocks with satisfactory performance while providing higher ecological and economic value.

Future research is recommended to explore a wider range of mixture compositions in order to identify the optimal proportion of pumice, sand, and cement that can achieve compressive strength comparable to conventional paving. In addition, long-term field testing is necessary to evaluate the performance of pumice-based paving under varying weather conditions, traffic loads, and abrasion levels. Further studies on the incorporation of additive materials such as latex, fly ash, or silica fume may enhance durability and reduce excessive porosity. Moreover, an environmental impact assessment through Life Cycle Assessment (LCA) is strongly recommended to strengthen the ecological benefits of pumice-based geo-paving.

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