Chemical Characterization of Pumice Material Sourced from Mbeya, Tanzania

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Abstract

Pumice, a lightweight volcanic material abundantly available in Mbeya, Tanzania, is underutilized and often discarded following excavation activities. In most construction projects within the region, conventional materials like clay soil, river sand, normal-weight aggregates, and cement are pre-dominantly used, leaving the potential of pumice largely unexploited. This study presents a comprehensive chemical characterization of pumice sourced from two locations, MUST main campus (Sample A) and Wimba (Sample B), to assess its suitability as a supplementary cementitious material (SCM). Energy Dispersive X-ray Fluorescence (EDXRF) analysis revealed that Sample A contained 70.3% SiO_2, 17.9% Al_2O_3, and 3.53% Fe_2O_3, while Sample B had 71.3% SiO_2, 17.3% Al_2O_3, and 3.38% Fe_2O_3. The combined SiO_2, Al_2O_3, and Fe_2O_3 content for both samples exceeded the 70% ASTM C618 threshold for pozzolanic materials, confirming strong pozzolanic properties. Additionally, K_2O was 5.21% in Sample A and 5.05% in Sample B, while CaO was 0.667% and 0.763%, respectively.SO_3 was detected at 0.448% (Sample A) and 0.482% (Sample B), and TiO_2 at 0.528% and 0.507%, respectively. Na_2O and MgO were not detected. The high levels of SiO_2 and Al_2O_3 suggest strong pozzolanic properties, while the low CaO content indicates that pumice would function primarily as a pozzolanic additive rather than a primary binder. Consequently, these findings confirm that pumice is better suited as a supplementary cementitious material (SCM) and filler rather than a complete replacement for cement. By partially replacing cement with pumice, it could be possible to reduce the carbon footprint, contributing to more sustainable construction practices.

Keywords: Pumice, chemical characterization, pozzolanic properties, supplementary cementitious material, XRF Analysis.

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1 Introduction

Construction materials play a crucial role in the development of infrastructure worldwide, with increasing emphasis on sustainable and locally available resources [1]. Tanzania, like many developing nations, faces challenges in balancing construction needs with environmental concerns and cost considerations [2]. Pumice, a naturally occurring volcanic material, presents an opportunity to address these challenges, particularly in regions where it is abundant, such as Mbeya, Tanzania [3].

Pumice, formed during volcanic eruptions when molten rock is ejected into the air and rapidly cools, is characterized by its highly vesicular structure, low density, and significant silica content [4]. These unique properties make it a promising candidate for various construction applications, particularly as a supplementary cementitious material (SCM) in concrete mixtures [5-7]. The lightweight nature of pumice, combined with its pozzolanic properties, allows it to serve as a sustainable alternative to traditional construction materials, reducing the overall carbon footprint of construction activities [8-10]. Furthermore, the use of locally sourced pumice can significantly lower transportation costs, support local economies, and align with broader sustainable development goals.

In previous research, a thorough review of the physical and chemical characteristics of pumice sourced from Georgia outlined its promising prospects for use in environmentally friendly lightweight concrete. By combining empirical data with practical implications, the study effectively argued for the adoption of pumice in modern construction practices, aligning with sustainable development goals [11]. This underscores the potential of pumice as a viable material for sustainable construction, not only in Georgia but also in other regions with similar geological resources, such as Tanzania.

Further studies have investigated the potential effects of physical, chemical, and electro-kinetic properties of pumice on the strength development of pumice-blended cements (PBC). It was found that a 30% replacement of clinker with pumice resulted in a 5–28% reduction in 28-day strength, depending on the characteristics of the pumice samples and grinding time [12]. This highlights the importance of optimizing the proportion of pumice in cement blends to achieve the desired mechanical properties. In another study, the influence of scoria and pumice on key performance indicators of Portland cement concrete was evaluated. The results revealed that scoria and pumice enhance concrete resistance to heat-induced strength degradation, preserve concrete performance indicators at reduced cement amounts, and modify the concrete microstructure, thereby lowering permeability [7]. These findings further support the use of pumice as a sustainable and effective material in construction.

Despite its potential, pumice remains largely underutilized in Tanzania, often treated as waste material during excavation activities [13]. This underutilization highlights a critical gap in the understanding of its chemical and physical properties, which are essential for determining its suitability for construction applications. The chemical composition of pumice, particularly its silica, alumina, and alkali content, plays a significant role in its performance as a construction material [5]. For instance, the pozzolanic reactivity of pumice, which enables it to react with calcium hydroxide in the presence of water to form cementitious compounds, is heavily influenced by its chemical makeup [7][14]. Therefore, a detailed chemical

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characterization of pumice sourced from Mbeya is necessary to unlock its full potential in the construction industry.

This study aims to provide a comprehensive chemical characterization of pumice material sourced from Mbeya, Tanzania, and to evaluate its suitability for construction applications. By analyzing its chemical composition, including major and trace elements, as well as its pozzolanic properties, this research seeks to establish a foundation for the optimized use of pumice in sustainable construction practices. The findings of this study could contribute to the development of more environmentally friendly building materials, reduce reliance on conventional resources, and promote the use of locally available materials in Tanzania's construction sector.

2 Materials and Methods

2.1 Study Area

The study focuses on pumice samples sourced from Mbeya, Tanzania, a region renowned for its volcanic activity and abundant deposits of pumice. Mbeya is situated in the southern highlands of Tanzania, a geologically active area charac-terized by the presence of volcanic mountains and rich mineral resources. The region lies at approximately 8.9°S latitude and 33.4°E longitude, with an elevation ranging from 1,000 to 2,900 m above sea level, contributing to its unique geologi-cal and climatic conditions [15].

Mbeya is part of the East African Rift System, a tectonically active zone that has given rise to numerous volcanic formations over millions of years. The re-gion's volcanic history has resulted in the widespread availability of pumice, a lightweight, porous volcanic rock formed during explosive eruptions. Pumice deposits in Mbeya are often found in areas surrounding volcanic craters and ash fields, making it a locally abundant and accessible resource [16].

The choice of Mbeya as the study area is strategic due to its significant pumice reserves, which remain largely underutilized despite their potential for sustainable construction applications. The pumice found in the region is typically extracted as a byproduct during excavation activities for other purposes, such as agriculture, building construction, or road construction, and is frequently discarded as waste material. The study area's unique combination of geological richness, economic potential, and environmental relevance makes it a compelling focus for research on sustainable construction materials.

2.2 Sample Collection and Preparation

Pumice samples were collected from two distinct sites in Mbeya, Tanzania. The first sample, designated as Sample A, was obtained from Mbeya University of Science and Technology (MUST) main campus, a location known for its proximity to volcanic formations and accessible pumice deposits. The second sample, Sample B, was collected from Wimba, a nearby area also rich in volcanic materials. Both sites were selected based on their geological significance and the availability of pumice in varying quantities and qualities.

As illustrated in Fig. 1, the collection process revealed that the depth at which pumice was obtained varied across different locations. At the MUST campus, pumice was found at approximately 2.1 m depth, beneath layers of top vegetable soil and moist blackish sand-silt soil (Fig. 1a). In Wimba, the deposit depth varied significantly between sites. At one site, pumice was found at a greater depth of 2.8 m, while at another, it was obtained at a shallow

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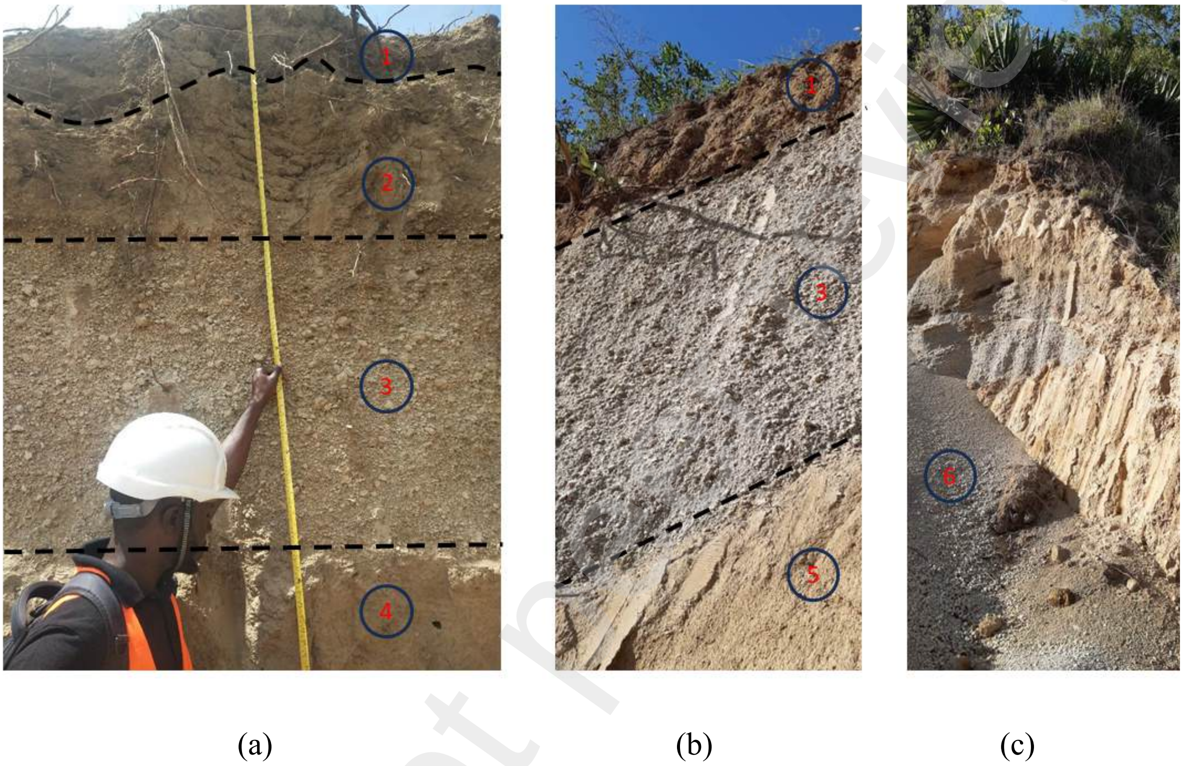
depth of 0.5 underlying top vegetable soil (Figure 1b). Additionally, pumice was observed in the excavated materials (6) from road construction activities in Wimba, as shown in Fig 1c. As shown in Fig. 1a and b, the stratigraphy includes top vegetable soil (1), moist, blackish sand silt soil (2), lightweight greyish pumice (3), moist, blackish sand silt soil (4), and moist, light brownish silt clay (5). The variability of pumice deposits high-lights the importance of site-specific evaluations to optimize its extraction and utilization in construction applications.



(a) (b) (c)

Fig. 1. Variations in pumice deposit depths at MUST Campus and Wimba (a) Pumice deposit at MUST campus (b) Pumice deposit at Wimba (c)Excavated pumice observed in road construction materials in Wimba.

Furthermore, the variations in depth and stratigraphy emphasize the heterogeneous nature of pumice deposits in the region and underscore the importance of collecting samples from multiple locations to ensure a comprehensive analysis. During the collection process, care was taken to ensure that the samples were representative of the pumice deposits in the region. The samples were gathered from shallow excavations to avoid contamination from underlying materials. Each sample was carefully labeled and documented, noting the location and depth.

Following collection, the pumice samples were transported to the Civil Engineering Laboratory of MUST for preparation. As shown in Fig.2, the preparation process involved several steps to ensure the samples were suitable for chemical analysis. First, the samples were thoroughly cleaned to remove any surface impurities, such as dust, soil, or organic matter. This was done using distilled water and gentle brushing to preserve the integrity of the pumice structure. Next, the cleaned samples were air-dried at room temperature for 48 hours to remove moisture. Once dried, the pumice was crushed into fine particles using a mechanical crusher. The crushed material was then sieved to obtain a uniform particle size, typically less than 75 microns, which is ideal for chemical analysis.

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(a) (b) (c)

Fig. 2. Preparation of pumice samples for chemical analysis (a) Air-dried pumice (b) Crushed dried pumice (c) Uniformly sieved pumice with a particle size less than 75 µm.

2.3 Chemical Characterization

Chemical characterization is a critical step in understanding the composition and potential applications of pumice as a construction material. In this study, X-Ray Fluorescence (XRF) analysis was employed to determine the elemental composition of pumice samples collected from Mbeya, Tanzania. XRF is a non-destructive analytical technique widely recognized for its accuracy and reliability in identifying and quantifying the chemical elements present in a material.

The XRF analysis focused on determining the concentrations of major oxides and trace elements in the pumice samples. The analysis was performed on samples A and B using Energy Dispersive X-Ray Fluorescence (ED-XRF) at the Government Chemist Laboratory Authority, Southern Highland Zone Office, Mbeya. The results of the XRF analysis, which are presented in Table 1, provide a detailed breakdown of the elemental composition of the pumice samples. These findings are discussed in detail in Section 3, where the suitability of pumice for construction applications, particularly as a supplementary cementitious material (SCM), is further evaluated.

3 Results and Discussion

3.1 Chemical Composition

The X-Ray Fluorescence (XRF) analysis conducted on pumice samples A and B revealed significant insights into their chemical composition, which is critical for evaluating their suitability as construction materials. The results, presented in Table 1, show the concentrations of major oxides and trace elements in the samples.

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Table 1. Chemical composition of pumice samples.

Sample ID	Results in mass %								
	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	CaO	TiO_2
A	70.3	17.9	3.53	ND	ND	5.21	0.448	0.667	0.528
B	71.3	17.3	3.38	ND	ND	5.05	0.482	0.763	0.507

3.2 Pozzolanic Properties and Implications for Construction

The major oxides analyzed included Silicon Dioxide (SiO_2), a key component of pozzolanic materials, essential for their reactivity with calcium hydroxide in cement. Aluminum Oxide (Al_2O_3) contributes to the strength and durability of cementitious materials, while Iron Oxide (Fe_2O_3) influences the color and chemical stability of the material. Calcium Oxide (CaO) plays a role in the hydration process of cement, and Magnesium Oxide (MgO) affects the setting time and volume stability of cement. Sodium Oxide (Na_2O) and Potassium Oxide (K_2O), as alkali oxides, can influence the reactivity and durability of the material. Additionally, Sulfur Trioxide (SO_3) impacts the setting time and strength development of cementitious materials, and Titanium Dioxide (TiO_2) contributes to the material's stability and durability, particularly in high-temperature applications.

The variation in chemical composition between Sample A and Sample B is minimal. It is evident from the chemical analysis (Table 1) that the main component of pumice for both samples is SiO_2 (i.e., 70.3% and 71.3% for Sample A and Sample B, respectively). According to ASTM C618 [17], the combined content of major oxides SiO_2, Al_2O_3, and Fe_2O_3 must be at least 70% for a material to qualify as a pozzolan. Both samples A and B meet this criterion, with combined percentages of 91.73% and 91.98%, respectively, indicating their potential as supplementary cementitious materials (SCMs).

4 Conclusions

This study conducted a comprehensive chemical characterization of pumice samples from Mbeya, Tanzania, to assess their suitability as sustainable construction materials. X-Ray Fluorescence (XRF) analysis revealed that both Sample A and Sample B contain high concentrations of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), with combined percentages of 91.73% and 91.98%, respectively. These values exceed the 70% ASTM C618 threshold for pozzolanic materials, indicating that the pumice samples have strong potential as supplementary cementitious materials (SCMs). The high levels of SiO_2 and Al_2O_3 in the pumice samples suggest strong pozzolanic properties, while the low calcium oxide (CaO) content indicates that pumice would function primarily as a pozzolanic additive rather than a primary binder. Consequently, pumice is more appropriate for use as an SCM and filler in construction applications rather than as a complete replacement for cement.

The absence of magnesium oxide (MgO) and sodium oxide (Na_2O) is beneficial, as these oxides can negatively affect setting time and durability in cementitious materials. Additionally, potassium oxide (K_2O), present at 5.21% (Sample A) and 5.05% (Sample B), poses a minimal risk of alkali-silica reactions (ASR), which can lead to concrete cracking. The sulfur trioxide (SO_3) content was 0.448% (Sample A) and 0.482% (Sample B), well within the 4% threshold, confirming that the pumice can be safely incorporated into cementitious mixtures without adverse effects.

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The study also highlighted variations in pumice deposit depths, with pumice found between 0.5 m and 2.8 m in Wimba and at approximately 2.1 m at the MUST campus. These variations emphasize the need for site-specific evaluations to optimize pumice extraction and utilization for construction applications.

Although the chemical composition of the pumice samples supports their use as SCMs, this study did not evaluate pozzolanic activity. Further research is needed to assess their reactivity with calcium hydroxide. Additionally, further research is underway to assess other properties of pumice, including its mineralogical, petrographic, and mechanical characteristics, as well as its performance in blended cement formulations. These investigations aim to determine the optimal mix design for producing lightweight blocks, further enhancing the application of pumice in sustainable construction materials.

In conclusion, Mbeya pumice exhibits potential as a locally available and sustainable construction material. Its use as a supplementary cementitious material can help reduce reliance on traditional cement, lower construction costs, and minimize environmental impacts. Integrating pumice into construction practices in Tanzania will support sustainable development goals while promoting the utilization of local resources.

During the preparation of this work the author(s) used ChatGPT in order to improve language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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