Archives of Environmental Sciences and Environmental Toxicology

Brahimi S, et al. Arch Environ Sci Environ Toxicol 7: 147.

www.doi.org/10.29011/2688-948X.100147

www.gavinpublishers.com

Research Article

Investigation of Natural Pozzolan and Perlite as Alternatives to Cement in Mortar

Sihem Brahimi[1*], Miloud Hamadache[2], Karim Benhabib[1]

[1]UPJV, EPROAD UR 4669, 7 Rue du Moulin Neuf, 80000 Amiens, France

[2]ENPO d'Oran, LABMAT – Laboratoire des Matériaux, Algérie

[*]**Corresponding author:** Sihem Brahimi, UPJV, EPROAD UR 4669, 7 Rue du Moulin Neuf, 80000 Amiens, France

Citation: Brahimi S, Hamadache M, Benhabib K (2024) Investigation of Natural Pozzolan and Perlite as Alternatives to Cement in Mortar. Arch Environ Sci Environ Toxicol 6: 147. DOI: 10.29011/2688-948X.100147

Received Date: 06 January 2024; **Accepted Date**: 08 April 2024; **Published Date**: 11 April 2024

Abstract

In this study, mineral materials sourced from northwest Algeria are examined as a specific case study. The main focus is on evaluating the feasibility of incorporating natural pozzolan and perlite as eco-friendly alternatives to traditional cement in the composition of mortar. The study involves assessing the mechanical properties and water absorption of the mortars at different time intervals. Additionally, scanning electron microscopy is employed to scrutinize the compositions and structures of the mortar. While mortars with pozzolanic elements initially exhibited reduced strength compared to the reference mortar, enhancements became evident over time. Despite a higher water absorption rate in pozzolanic mortars, the addition of 10% perlite resulted in the least absorption among all pozzolanic mixes. The research underscores the potential of natural pozzolan as an eco-friendly substitute for cement in mortar applications, emphasizing its viability and substantial contributions to environmentally conscious construction practices.

Keywords: Perlite; Pozzolan; Mortar; Mechanical strength; Water absorption

Introduction

Eco-mortar is a type of mortar made from environmentally friendly materials, including recycled and natural ingredients. The use of such materials can help to reduce waste and the carbon footprint associated with construction. Eco-mortar provides an alternative to traditional mortar, which typically includes cement, sand, and water. In addition to being eco-friendly, eco-mortar offers several other benefits [1]. For instance, it is more resistant to cracking and shrinking than traditional mortar and provides better insulation. It is also more breathable, preventing moisture buildup and enhancing indoor air quality.

Furthermore, eco-mortar may have other advantages that make it a promising option for sustainable construction [1]. It can be customized to fit specific requirements, such as different colors and textures [2], and it can be used for a variety of applications, including masonry, plastering, and tiling. Additionally, it has a longer lifespan and requires less maintenance than traditional mortar, which reduces the overall cost of construction.

Eco-mortar also has a lower embodied energy, meaning that it requires less energy to produce and transport, which further reduces its environmental impact. With the growing demand for sustainable building materials, eco-mortar is an excellent option for reducing the environmental impact of construction while still delivering high-quality results [3].

This study aims to explore the potential of natural pozzolan and perlite as eco-friendly alternatives to cement in material design, considering the detrimental environmental impact of cement production. Despite being widely used in the construction industry due to its affordability, cement production is associated with high energy consumption, greenhouse gas emissions, and environmental pollution Therefore, exploring and using alternative natural materials that are abundantly available can help reduce pollution and production costs. This approach, known as substituting cement with natural materials [1,4], is crucial for promoting sustainable construction practices. By investigating the properties and potential of natural pozzolan and perlite as cement substitutes, this study can contribute to the development of more sustainable and environmentally friendly construction practices.

On the one hand, the ASTM C 125 norm (2007) [5] defines pozzolan as a siliceous or siliceous-aluminous material that lacks binding properties on its own. However, when exposed to moisture, it can react chemically with calcium hydroxide to form compounds that have binding properties. This makes pozzolan an essential ingredient in sustainable construction practices, as it can partially replace cement. By reducing the amount of cement used in building materials and replacing it with pozzolan, construction-related carbon emissions can be significantly reduced, contributing to a more sustainable future. Pozzolan is widely used in the construction industry due to its cost-effectiveness, durability, and ability to improve the performance of mortar, such as enhancing compressive strength, reducing permeability, and improving chemical resistance [6,7,8].

On the other hand, perlite is a naturally occurring volcanic glass that forms when lava cools rapidly. It is a lightweight and porous material that is often used as an aggregate in construction materials such as concrete, mortar, and plaster [1,2,9,10]. Expanded perlite is valued for its excellent insulation properties, fire resistance, and ability to reduce the weight of concrete without compromising its strength [9]. When added to concrete or mortar, perlite creates air pockets that improve thermal insulation, increase acoustic insulation, and reduce weight, making it an eco-friendly alternative to traditional building materials [2,6,11,12]. Furthermore, perlite is non-toxic, does not deteriorate over time, and is resistant to pests and rodents [1,9]. Its numerous benefits make it a highly sought-after material in sustainable construction.

Algeria possesses significant deposits of pozzolanic and perlite materials, making it a prime location for sustainable and cost-effective alternatives to traditional building materials [13]. Particularly, in [14,15] some studies were conducted in Algeria for exploring the potential of these materials.

Researchers from around the world have also investigated various types of pozzolanic materials, providing valuable information into their properties and performance. For example, in India [16], the authors investigated the use of fly ash, a by-product of coal combustion, as a potential pozzolanic material for eco-friendly concrete production. Furthermore, in [17], the authors showed that a partial replacement of up to 15% with perlite in the fine aggregate can achieve the desired strength while reducing overall density. In Vietnam, researchers have explored the application of a unique type of natural pozzolan as a partial substitute for cement in heavyweight concrete [18]. The study revealed that although the concrete with natural pozzolan exhibited slightly lower strengths compared to the control concrete at various stages of curing, it significantly improved the workability of fresh concrete by up to 16.67%. It should be mentioned that the optimal pozzolanic mortar contains a maximum of 20% substitution, ensuring the desired properties.

In Saudi Arabia [19], the authors analysed the effects of natural pozzolans and limestone powder on cement paste and mortar properties, with a focus on the resulting chemical changes. In this case, thermal, chemical, and microstructural analyses confirmed the role of both substitutes in controlling reaction kinetics and forming new hydration products.

Moreover, in a study conducted by [1] in Turkey, the potential of natural perlites as an additive in blended cement production was investigated. After evaluating the pozzolanic properties and grindability of perlites, various types of blended cements were produced with different levels of substitution and Blaine fineness using inter-grinding or separate grinding methods. The study concluded that perlites possess strong pozzolanic properties and are a viable option for blended cement production.

One study in this field, conducted in [14], examined mortars made with cement containing natural pozzolana extracted from an Algerian deposit. The study found that including a water-reducing superplasticizer (in percentages varying from 0 to 3%) was necessary to improve mechanical properties. The experiments conducted in this work confirm these results. The aforementioned study also showed that natural pozzolan accelerated the hydration process and promoted the formation of more C-S-H, which bonded to Portlandite $Ca(OH)_2$. This resulted in greater delayed deformations compared to a reference (control) mortar. However, mortars with pozzolanic substitution, having a lower cement content and higher water/binder ratio, experience more intense water evaporation than a reference mortar, which can affect workability and overall mechanical properties. This should be considered when designing mixtures with pozzolanic materials.

In a related study [15], the authors investigated the influence of varying pozzolana content (20%, 25%, and 30%) on the properties of pozzolanic cement mortars, along with a control mortar. The study revealed that the pozzolanic mortars set more rapidly than the reference mortar, indicating that the presence of pozzolana enhances C3S hydration. However, the air content of the pozzolanic mortars was higher, which may be attributed to the variation in fineness resulting from the pozzolana. In addition, while the mortar containing 20% pozzolana showed mechanical properties comparable to those of the reference mortar, the mechanical properties of mortars with higher pozzolana content (25% and 30%) were somewhat lower. Therefore, in this study, the primary focus was on maintaining the optimum 20% pozzolana substitution, which is essential to ensuring optimal mechanical properties while maximizing the cost-effective and sustainable use of natural pozzolana in construction.

According to [20], further investigation remains necessary to determine the effects of using perlite in various types of blended cements, including those containing different types of clinker or supplementary cementitious materials. The study reported that incorporating Algerian perlite powder as a substitute for cement is able to increase the normal consistency and to decrease the workability of mortars, requiring the use of a superplasticizer. The so-called optimal substitution percentage with perlite is closest to 20% by weight of cement.

Finally, a preliminary study conducted in [21] explored the mechanical properties, specifically the short-term compressive strength, of pozzolanic mortar with partial substitution of cement using perlite and/or pozzolan powders. The substitution varies from 10% to 20%, based on the most appropriate percentage observed in the literature. The study also examined water absorption as a durability factor. The provided results showed that pozzolanic mortars containing 10% of perlite achieved superior short-term strength compared to the other tested mortars.

Contribution

The successful combination of natural pozzolana and perlite has been demonstrated in several previous studies, including the work conducted in [22], which investigated the use of these materials as partial replacements for cement in concrete. The authors showed that they can enhance the mechanical properties and durability of mortar. To ensure the accuracy and validity of the proposed study, a comprehensive series of tests are conducted on the developed pozzolanic mortar. The tests include assessing the mechanical properties such as compressive and flexural strengths, measuring water absorption, and evaluating the microstructure of the mortars using advanced techniques such as scanning electron microscopy (SEM) and EDS analysis.

In this study, the so-called optimal mass substitutions of cement by natural pozzolana and perlite powders are determined based on previously established results available in the literature, with a maximum substitution level of 20% [22,23]. These natural materials will be combined in varying proportions to achieve the desired properties of the final mortars. The potential of natural pozzolanic materials, including natural pozzolan and natural perlite as sustainable alternatives to the more recent Portland cement (CEM I 52.5 N) in the development of high-performance construction materials, are investigated.

To achieve this goal, the study consists of three complementary parts:

- A Scanning Electron Microscopy (SEM) analysis is conducted to achieve a better understanding of the morphology and microstructure of the developed mortars. This method provides detailed information on the morphology and elemental composition of the samples, helping to identify the mechanisms responsible for the observed properties.
- An analysis of the compressive and bending strengths of natural pozzolanic mortar is undertaken over both the short-term (7, 14, and 28 days) [21] and long term (56, 90, and 130 days). The aim is to evaluate the performance of the mortar over time and assess its suitability for use in sustainable building practices.
- Additionally, water absorption is examined by comparing the results related to the standard mortar and the mortars containing natural pozzolan and/or natural perlite powders as cement substitutes. Apart from discussing the results for 24 days, the study was extended to cover different time periods, ranging from 5 minutes to 26 hours. Of course, the investigation related to this study aims to assess the mortar's ability to resist water penetration over time, a critical factor in determining the material's durability and resistance to moisture-related damage.

Finally, the results of this study are believed to provide valuable information about the potential of natural pozzolanic materials as sustainable alternatives to cement and their contribution to the development of eco-friendly construction materials.

Materials and Methods

This section provides detailed information on the materials used in this study, including their characteristics and the process for preparing the mortars for testing. The formulation of all considered mortars is also discussed; that is essential for understanding the properties and behavior of the mortar in the subsequent sections of the study. Of course, the information provided in this section is critical for accurately interpreting the results and drawing meaningful conclusions about the performance of the mortars.

Materials

The cement

This section provides comprehensive information about the more recent Portland cement used in the study. Specifically, CEM I 52.5 N cement is used, which meets the standard EN 197-1 [24]. The cement has a Blaine specific surface area of 4060 cm^2/g, indicating its high fineness. In addition, Table 1 shows the chemical composition of the cement, which is critical to understanding its properties and potential performance in subsequent tests.

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	MnO	Cl^-	TiO_2	P_2O_5
Content (%)	19.6	5.3	2.7	63.8	2.4	3.6	2.4	0.1	0.04	0.0	0.3	0.7

Table 1: Chemical composition of the more recent cement CEM I 52.5 N.

The mineralogical composition of the cement was also analyzed using the Bogue method, and the results of this analysis are reported in Table 2. The mineralogical composition is crucial in understanding the behavior and properties of the cement and resulting mortars, which is why this specific cement was selected for the study.

Components	C_3S	C_3A	C_2S
Content (%)	69.9	8.5	8.3

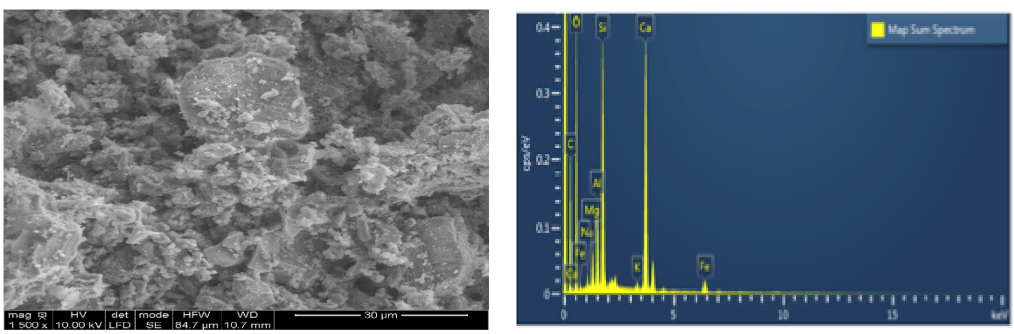
Table 2: Mineralogical composition of the clinker.

The sand

Sand is a critical component of the granular skeleton that significantly impacts the quality of mortar. For this study, Ultibat masonry sand was used, adhering to the French standard EN 12620+A1 [25]. This type of sand has a bulk density of 1600 kg/m^3 and a grain size ranging from 0 to 4 mm, which makes it well suited for masonry mortar applications. The selection of Ultibat sand ensures the enhancement of mortar quality. Understanding the properties of the sand used in this study is crucial for evaluating the behavior and performance of the mortar in subsequent tests.

The natural pozzolan

Algeria has a significant amount of pozzolanic materials of volcanic origin, which are mainly used by a few cement plants. In this study, the natural pozzolan used was extracted from Beni-Saf in Algeria.



(a) (b)

Figure 1: (a) Scanning electron micrograph of pozzolan (G=1500) and **(b)** its EDX analysis.

The natural pozzolan used in all test scenarios is a powder derived from crushed pozzolanic slag (Figure 1.a, with an enlargement factor of G=1500). This pozzolan undergoes an initial 24-hour steaming process at a temperature of 50°C to eliminate moisture, followed by grinding until the resulting powder achieves the fineness necessary to pass through an 80 µm mesh sieve. Small amount of pozzolan sample ground powder were attached on the surface of aluminum SEM stubs using double-sided carbon tape. The specimens were examined under low-vacuum mode.

Comprehending the chemical composition of the natural pozzolan is crucial for a thorough understanding of the mortars' behavior in the study. Accordingly, the results from EDX analysis (Figure 1.b) and Table 3 show a significant percentage of silica (42.95%) in the chemical composition of the pozzolan material, along with a low sulfur (SO_3) content and an absence of chloride (Cl-).

The natural pozzolan employed features a Blaine specific surface area of 4330 cm²/g and an absolute density of 2660 kg/m^3.

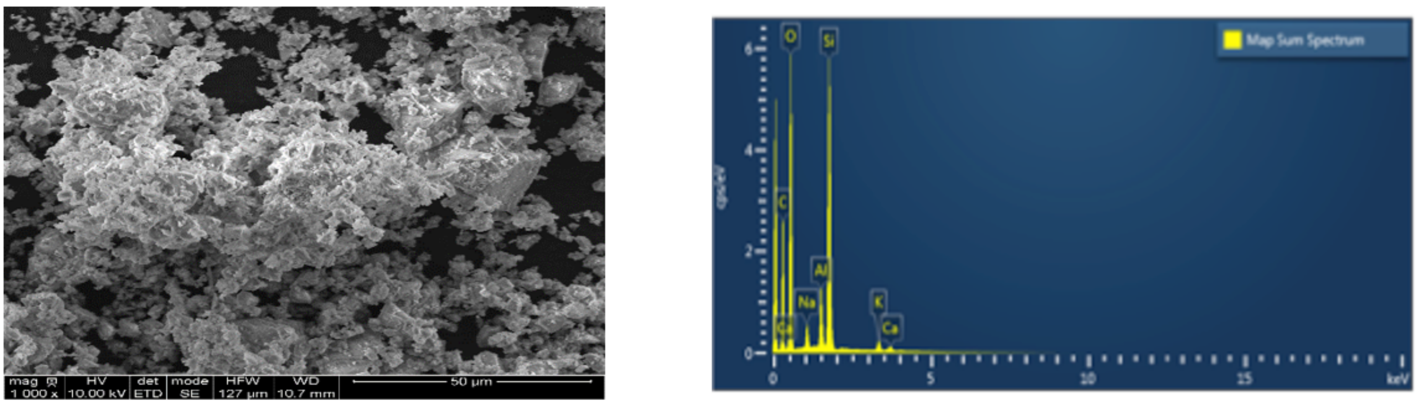
Components	SiO_2	CaO	Al_2O_3	Fe_2O_3	SO_3	K_2O	Na_2O	MgO	Cl^-	$CaCO_3$
Content (%)	42.95	12.36	16.32	9.49	0.01	1.39	3.00	4.20	0.00	10.75

Table 3: Chemical composition of natural pozzolan [26].

The Natural Perlite

The perlite is a siliceous volcanic rock that is extracted from the Tlemcen deposit in Algeria [22]. The natural perlite used in all tests is also a powder provided from crushed perlite slag (Figure 2a). The perlite is first steamed for 24 hours at a temperature of 50°C to remove moisture. In this study, the 80 µm fraction is used for all tests [20].

To gain a better understanding of the behavior of natural perlite in this study, the chemical composition of the ground perlite is presented in Table 4. These results and EDS analysis (Figure 2b) show that the amount of silica is greater than 76%, with aluminum representing 13.43%, while chloride (Cl-) and sulfur (SO_3) are present in negligible amounts.



(a) (b)

Figure 2: (a) Scanning electron micrograph of perlite (G=1000) and **(b)** its EDX analysis.

The Blaine specific surface of the perlite is equal to 4060 cm²/g, and its absolute density is equal to 0.0243 kg/m³ (such a surface is comparable to that of cement).

Components	**SiO_2**	**CaO**	**Al_2O_3**	**Fe_2O_3**	**SO_3**	**K_2O**	**Na_2O**	**MgO**	**Cl^-**	**FeO**
Content (%)	76.40	3.16	13.43	2.92	0.01	4.33	0.82	0.37	0.00	8.75

Table 4: Chemical composition of natural perlite [26].

Preparation of Mortars

The preparation of the mortars adhered to the guidelines of the standard EN 196-1. (2006). A practical formulation was employed for all mortars, involving the mixing of sand and the tested cement with water in the following proportions: 450 ± 2g of cement, 1350 ± 5g of sand, and a water-to-binder ratio of 0.50. In this study, a certain percentage of cement was replaced with pozzolan, perlite, or a combination of both. However, preliminary tests revealed water absorption in the resulting mortars. To address this issue, a water-reducing superplasticizer/admixture (Ultibat brand) was added at a mass percentage of 1% of the cement to enhance workability.

Each mortar mixture was used to create three specimens with dimensions of 4×4×16 cm³, following the standard (EN 196-1, 2006). The specimens underwent curing under controlled conditions, maintaining a temperature of T = 20 ± 2°C and a relative humidity of 98%. Cure times were 7, 14, and 28 days for short-term testing and 56, 90, and 130 days for long-term testing. The experiments conducted in this work used the following nomenclature:

- M represents "Mortar", followed by either 10 or 20 to indicate the percentage of cement substitution.
- PZ (or P) for "Pozzolan" ("Perlite") indicates the type of pozzolanic substitute.
- The reference mortar is denoted as M0, representing the mortar without any substitution of pozzolanic materials.

Characterization Methods

Microstructural Analysis

An environmental scanning electron microscope (ESEM, FEI Quanta 200 FEG, USA) equipped with an energy-dispersive X-ray microanalyzer (EDX, X-Max 80, Oxford Instruments Co., UK) was used from the microscopic platform of the University Jules Verne of Picardie. Additionally, another scanning electron microscope (TM-1000) from the University of Tlemcen was employed for the surface morphological and chemical characterization of natural pozzolan and perlite.

Mechanical Strengths

Bending strength, also known as flexural strength, is a crucial property that determines the maximum amount of stress a material can withstand before it bends or breaks under a bending load. Of course, the bending strength of a material is usually measured by subjecting a specimen to either a three-point or a four-point bending test. In this study, the three-point bending test was conducted to determine the bending strength of the material.

The compressive strength test is another critical property of a material, which determines the maximum amount of compressive stress that a material can withstand before fracturing or failing. In this study, the compressive strength test was conducted to assess the quality and durability of the resulting material.

The bending and compressive strengths of the mortars were measured in accordance with EN 12390-3 [28], using test specimens with dimensions of 4x4x16 cm³. For bending strength, three samples were tested. Then the compressive strength of the six pieces generated by the bending test was measured. The three-point bending measurements were conducted using a "Shimadzu hydraulic apparatus", which can apply a maximum load of 10 kN. To conduct the compressive tests, a "Proviteq hydraulic press" with a maximum compression capacity of 250 kN and a force servo rate of 2400 N/s ± 200 N/s was used.

Water absorption analysis

The test specimens used in this study had dimensions of 4 x 4 x 16 cm³ and were cured for 28 days at a controlled temperature of 20 ± 2°C and a relative humidity of 98%. Following the curing process, the specimens were dried at 50°C and then immersed in water for 26 hours, weighed periodically at 5 minutes, 1 hour, 2 hours, 4 hours, 8 hours, 24 hours and 26 hours. This immersion process is necessary to determine the water absorption capacity of the mortars, which is one of the important parameters for assessing their durability and resistance to moisture.

The test involved measuring the amount of water absorbed by the mortar, the water absorption coefficient, and the porosity of the samples. By analyzing the values obtained from the test, it was possible to determine how the proportion of pozzolanic materials affects the water absorption properties of the mortar. To ensure consistent and reliable test conditions, the NF ISO 15148 standard [29] was followed.

Results and Discussion

Mechanical Strengths

Compressive Strength

The results of the tests carried out in this study are presented in Figure 3, which shows the evolution of compressive strength as a function of curing time, either in the short-term (7, 14 and 28 days) or in the long-term (56, 90 and 130 days). The representative bars of the mortars M0 (reference), M10PZ (binary), M10P (binary), M20PZ (binary), M20P (binary), and M10P10PZ (ternary) provide interesting information into the variations observed in the study.

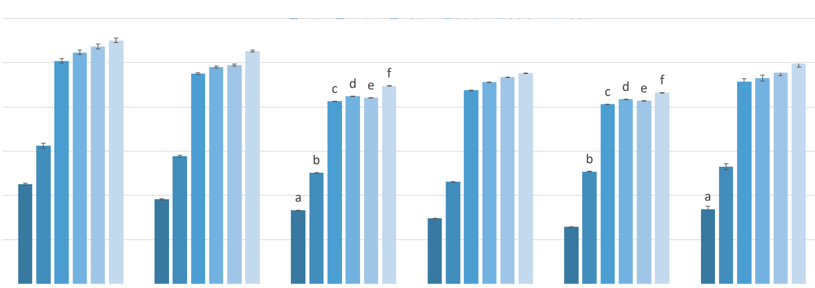
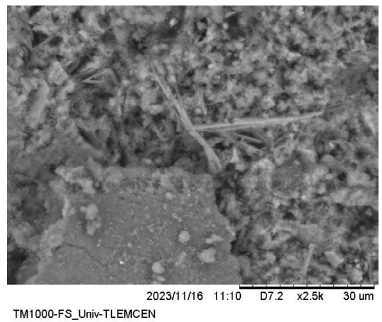


Figure 3: Evolution of the compressive strength as a function of cement substitution type and curing time. For a given curing time, formulations labeled with the same letter do not show a significant difference (p-value < 0.05).

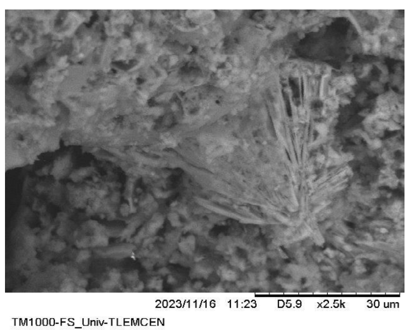
Regardless of the mortar formulation, the study concerning short-term effects [21] reveals that the compressive strength increases steadily with curing time. While for the long-term, although the compressive strengths of the pozzolanic mortars continue to increase as the curing time progressed, this increase becomes less pronounced after 28 days. Moreover, pozzolanic mortars show a continuous improvement in compressive strength over time.

As highlighted in [1,16,21] regardless of curing time, the compressive strength of pozzolanic mortars remains lower as compared to the compressive strength of the reference mortar. The decrease in strength can be primarily attributed to the slow reactivity of the pozzolan [30,31]. This phenomenon occurs due to the interaction between the reactive silica found in the vitreous part of the pozzolan and the $Ca(OH)_2$ released during cement hydration. This interaction facilitates the binding of natural and artificial pozzolans with lime, thereby granting them the property of lime fixation.

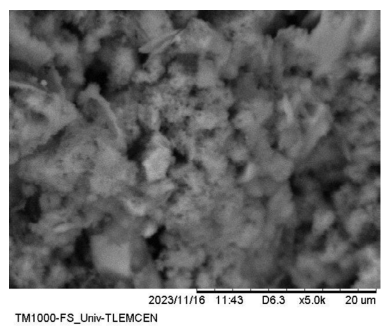
At short term this decrease has been attributed to the observed porosity of mortars [21]. As observed in previous studies [1,32], it could be also noticed that the rate of pozzolana materials has an impact on the strength. As the rate increases, the compressive strength decreases. Furthermore, a correlation has been identified between the rate of pozzolana substitution and strength.



(a)



(b)



(c)

Figure 4: Observation of mortars compactness by scanning electron microscopy (G=2500): **(a)** M0, **(b)** M10P and **(c)** M10P+10PZ.

While pozzolanic mortars illustrate lower compressive strengths than the reference mortar in both short and long-term, their substantial compressive strengths highlight the efficacy of pozzolanic substitution in maintaining certain mechanical properties of the mortars.

Among the pozzolanic mortars, those with 10% substitution, both binary (M10P and M10PZ) and ternary (M10P+10PZ), show the highest compressive strengths. Therefore, the most favorable results are observed in mortars where 10% of perlite is substituted.

Upon microscopic examination, it becomes evident that these three mortars display satisfactory adhesion between the sand aggregate and matrix. Furthermore, the compactness of the M10P mortar closely mirrors that of the reference mortar M0 (Figure 4a and Figure 4b), whereas the ternary mortar (M10P+10PZ) displays micro-porosity (Figure 4c).

Considering the relatively low cost of extracting pozzolanic materials in Algeria, mortars obtained by substituting 10% of cement with perlite could be potentially competitive. However, if extracting pure perlite is challenging and costly, the substitution may lack economic advantages. Evaluating the reduction of waste and the associated carbon footprint is crucial for assessing the overall applicability and merits of the use of the new material.

Furthermore, the higher proportion of the Ca element in species developing in the pozzolanic mortar matrix is likely due to the interaction between reactive silica in the vitreous part of the pozzolan and the $Ca(OH)_2$ released during cement hydration. The aforementioned interaction facilitates the binding of natural and artificial pozzolans with lime, potentially explaining the slight reduction in compressive strength compared to the reference mortar. Moreover, this phenomenon may clarify the observed trend that a higher rate of cement substitution leads to a greater reduction [30,31].

Additionally, the above phenomenon can be attributed to the pozzolanic activity, which is slow in its early stages and develops over the long term by fixing the portlandite Ca $(OH)_2$ released during the hydration of Portland cement. Such a process gives rise to additional second-generation C-S-H, occupying a significant space in the cement matrix and contributing to strength development, as indicated in the literature [33].

Bending Strength

Figure 6 illustrates a comprehensive overview of the bending strengths of the various mortar formulations at different curing times.

On the one hand, the results presented in this study confirm those of the study conducted for the short-term [21]. The bending strength of pozzolanic mortars is lower than that of the reference mortar. In this case, the largest deviation from the reference mortar is observed with an increase factor of 3.60, ranging between 3.48 MPa and 12.50 MPa.

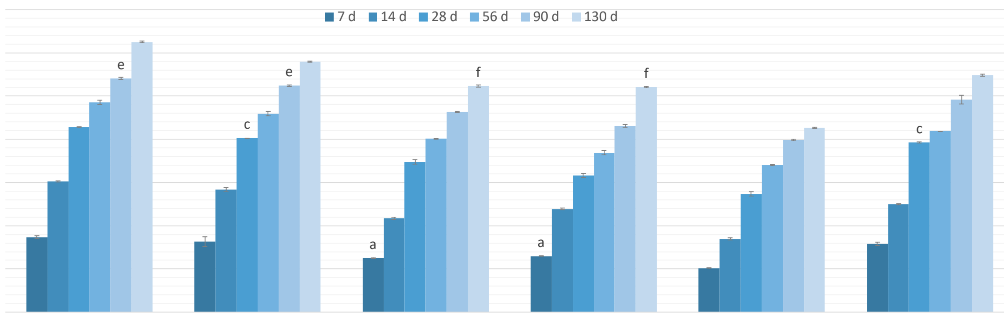


Figure 6: Evolution of the bending strength as a function of cement substitution type and curing time (for a given curing time, formulations labeled with the same letter do not show a significant difference with p-value < 0.05).

Figure 6 shows that the bending strength of mortars, whatever their composition, increases according to their age. The bending strength analysis revealed the potential contribution of perlite's structure (as illustrated in Figure 6) to the enhancement of the mechanical strength in the produced mortars. Pozzolanic mortars with a percentage of perlite substitution, namely M10P, M20P, and M10+P10PZ, display better bending strength.

Among all mixtures, M10P provides the highest bending strength, which is close to the reference mortar M0. However, M10P+10PZ, a cost-effective pozzolanic mortar, also achieves an interesting bending strength.

Note that the increase in strength can be primarily attributed to the enhanced reactivity of the pozzolan [30,31]. This phenomenon may arise from the interaction between the reactive silica present in the vitreous part of the pozzolan and the Ca $(OH)_2$ released during cement hydration.

The provided results are consistent with previous studies on the use of natural pozzolana and perlite in concrete production (e.g., [22]), where the addition of natural pozzolana and perlite improved certain mechanical properties and durability of blended cement. Hence, the study shows that natural perlite can be used as a partial replacement of cement for mortar production.

The achieved results are also in accordance with the conclusions of previous work on cements [33]. Furthermore, the experimental results of this paper show that the physical characteristics of the cement containing natural pozzolana meet the requirements outlined by standards. It is observed that the strength of pozzolanic cement was lower than that of plain Portland cement in the early stages, but it could achieve comparable strength levels at longer-term ages.

Exploring the relationship between bending and compressive strengths

The correlation between bending and compressive strengths is a significant aspect of material analysis and structural design. Understanding the relationship between bending and compressive is crucial for predicting material behavior under various loading conditions and designing structures that are capable of withstanding both bending and compression.

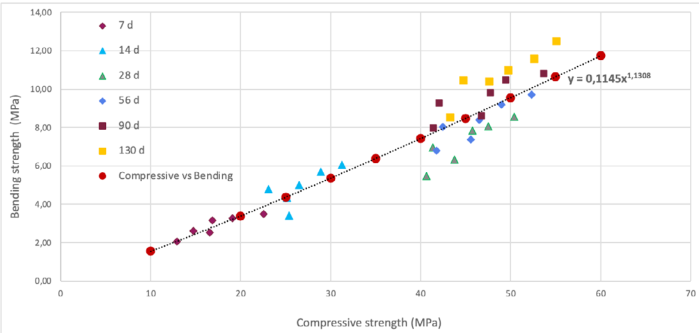


Figure 7: Relationship between bending strength and compressive strength.

Figure 7 illustrates the relationship between bending strength (f_b) and compressive strength (f_c), as used in [33].

A statistical analysis is conducted to calculate the correlation coefficient (r) and estimate the values of k and α. The analysis is based on a dataset provided by the experimental study that includes both bending and compressive strengths values. The results reveal a strong correlation, indicated by a correlation coefficient of r=0.94. Additionally, the calculated values for k and α are k=0.1145 and α=1.1308, respectively. Consequently, the formula can be rewritten as follows:

$f_b=0.1145\times (f_c)$^1.1308

These results seem to be in accordance with the relationship established in previous studies [34].

Water Absorption

Water absorption is a crucial property of materials, and it is typically measured by assessing the amount of water a material can absorb under specific conditions. In this study, we focused on water absorption as a key property of the proposed mortar, which is composed of cement, sand, water, and natural pozzolanic materials.

Analysis of the water absorption

To evaluate water absorption, the mortar specimens are immersed in water for 5 minutes, 20 minutes, 2 hours, 4 hours, 8 hours, 24 hours and 26 hours.

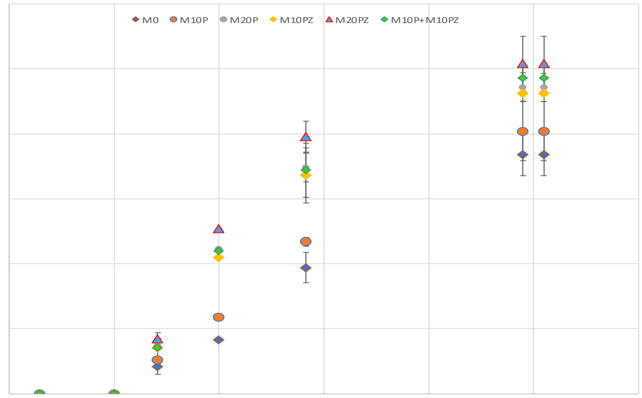


Figure 8: Evolution of the water absorption versus curing time.

Figure 8 illustrates the provided water absorption results. The figure shows that all pozzolanic mortars display higher final water absorption values compared to the reference mortar. The M20P, M20PZ, and M10P+M10PZ mortars show a faster water absorption rate than the M10P and M0 mortars. Moreover, the water absorption values for M20P, M20PZ, and M10P+M10PZ show no significant variation, which also holds true for M0 and M10P.

Therefore, the outcomes from the water absorption test suggest that the inclusion of pozzolanic materials does not improve the water resistance of the mortars. Incorporating a small proportion of perlite (10%) does not lead to a substantial increase in water absorption for the mortar, as observed in comparison to the reference sample.

Water absorption coefficient and apparent porosity analysis

The results in Table 5 report the water absorption (Wmax), the water absorption coefficient (Ac) and the apparent porosity values (P) of all mortar samples.

Composites	M0	M10P	M20P	M10PZ	M20PZ	M10P+10PZ
Wmax (%)	1.835±0.163(abc)	2.022±0.229(de)	2.359±0.110(a)	2.316±0.050(a)	2.542±0.209(ce)	2.435±0.109(bd)
Ac ($kg.m^{-2}.s^{-1/2}$, 10^{-3})	1.043+0.091(abc)	1.221+0.136(e)	1.496+0.136(b)	1.299+0.000(a)	1.614+0.068(ce)	1.418+0.118(b)
P (%, 10^{-3})	3.451±0.298(abc)	4.036±0.451(d)	4.948±0.451(ad)	4.297±0.000	5.339±0.225(b)	4.688±0.390(ad)

Table 5: Parameters of water absorption kinetics by imbibition of the different composites (formulations labeled with the same letter show a significant difference with p-value < 0.05).

In the case of mortar samples with perlite substitution, the M10P mortar yields a slightly higher water absorption coefficient than the reference mortar (M0), as shown in Table 5. Consequently, it also shows a slightly higher porosity value. Similarly, the water absorption coefficients of the other binary mortars (M10PZ, M20P, and M20PZ) follow a uniform distribution, with an increasing order corresponding to their porosity coefficients.

However, the tertiary mortar M10P+M10PZ provides the fourth-higher water absorption coefficient compared to all other pozzolanic mortars. Its porosity coefficient is closer to that of M20P and remains comparable to that achieved by both M10PZ and M20PZ. The SEM morphology images suggested that this phenomenon could be attributed to the better distribution of perlite particles throughout the mortar matrix in M10P+M10PZ, creating a more uniform pore structure that facilitated improved water drainage. This observation underscores the potential advantages of using a combination of perlite particle sizes in mortar mixes, as it allows for optimization of both porosity and water absorption properties.

Conclusions and Perspectives

This study aimed to examine the influence of natural perlite and natural pozzolan powders, both extracted from Southwest Algeria, as cement substitutes on the mechanical behavior, water absorption, and microstructure of pozzolanic mortars.

The implementation of the scanning electron microscopy (SEM) method facilitated a comprehensive analysis of the specimens' surface morphology and elemental composition. This advanced technique provided detailed information that played a crucial role in identifying the underlying mechanisms responsible for the observed properties.

In order to evaluate the performance of the mortars over time, both short-term (7, 14, and 28 days) and long-term (56, 90, 130 days) compressive and bending strength tests were conducted.

The results showed that initially, the compressive and bending strengths of the pozzolanic mortars were lower compared to the reference mortar; that is the mortar without any substitution (M0). However, as time passed, there was an improvement in the strength characteristics of the pozzolanic mortars, especially in the long-term. Among the different mortar compositions, the one containing 10% of natural perlite provided the highest compressive strength. It was closely followed by the mortars containing 10% of natural pozzolan and those containing a combination of both substitutes. Similarly, the pozzolanic mortars containing 10% of perlite or/and of pozzolan displayed superior bending strengths compared to the other tested pozzolanic compositions.

In terms of water absorption, the pozzolanic mortars provided higher values compared to the reference mortar M0, with the exception of the mortar containing 10% of perlite, which displayed a slightly higher value than that of M0. This suggests that a substitution with a small perlite percentage may have a reduced impact on water absorption and durability.

The pozzolanic mortars developed in this study had higher open porosity than the reference mortar M0, which may affect their durability. However, previous studies have shown that substituting cement with perlite reduces porosity and leads to increased mechanical strength and durability over time.

Future research could include studying the shrinking test to evaluate the dimensional stability of materials during and after a drying process, providing interesting information into the durability of the pozzolanic materials. Evaluating the effects of other natural (and synthetic) pozzolanic materials on the properties of mortars would also be valuable. Another interesting study within the construction field could involve exploring the impact of corrosion on pozzolanic materials. This direction of research would allow for a better understanding of the mechanisms by which corrosion affects the structural integrity, properties, and durability of these materials.

Finally, these research perspectives can have significant implications for the durability and performance of the pozzolanic materials examined in this study. They can also contribute to a better understanding of the optimal percentage of pozzolanic substitutes for specific applications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data will be available upon request.

Acknowledgements.

This work was supported by the LAB laboratory in Algeria.

References

1. Dif F, Douara TH, Zaitri R, Mouli M (2020) Effects of combined natural volcanic powders on the thermo-physical and mechanical properties of structural eco-concrete. Journal of Building Engineering. 32:101835.

2. Meral Ç (2004) Use of perlite as a pozzolanic addition in blended cement production, PhD Thesis on Science. University Technique of Middle Est.

3. Erdem TK, Meral Ç, Tokyay M, Erdoğan TY, (2007) Use of perlite as a pozzolanic addition in producing blended cements, Cement Concrete Composite. 29: 13-21.

4. Desarnaud E, Desbarbieux T, Ando S, Prebay Y, (2006) Atelier Changement Climatique : Les enjeux du développement durable au sein de l'Industrie du Ciment : réduction des émissions de CO_2.

5. ASTM C 125: (2007) Standard Terminology Relating to Concrete and Concrete Aggregates American Society for Testing and Materials.

6. Yu L-H, Ou H, Lee LL, (2003) Investigation on pozzolanic effect of perlite powder in concrete. Cement Concrete Composite. 33: 73-76.

7. Ghrici M, (2006) Etude des propriétés physico- mécanique et durabilités des ciments à base de la pouzzolane naturelle. Thèse de doctorat, USTMBO.

8. Kaid N, Cyr M, Julien S, Khelafi H, (2009) Durability of concrete containing a natural pozzolan as defined by a performance-based approach. Construction and Building Materials. 23: 3457-3467.

9. Rashad AM, (2016) A synopsis about perlite as building material - A best practice guide for civil engineer. Construction and Building Materials. 121: 338-353.

10. Kramar D, Bindiganavile V, (2016) Impact response of light weight mortars containing expanded perlite. Cement and Concrete Composites. 37:205-214.

11. Erdem E, (1997) Effect of various additives on the hydration of perlite gypsum plaster and perlite- Portland cement pastes. Turkish Journal of Chemistry. 2: 209-214.

12. Erdogan ST, Saglık AÜ, (2013) Early-age activation of cement pastes and mortars containing ground perlite as a pozzolan". Cement and Concrete Composites. 38: 29-39.

13. Renac C, Mexias A, Louni-Hacini A, Brouillet S, Cottin JY, (2014) Rhyolite petrogenesis and meteoric–hydrothermal alteration at the Maghnia volcanic massif. Northwest Algeria. Journal of Geochemical Exploration. 143: 1-18.

14. Kaid N, (2000) Contribution à l'étude des caractéristiques physico-chimiques et mécaniques des mortiers pouzzolaniques, PhD Thesis, Université Mohamed Boudiaf Oran.

15. Laoufi H, Dif F, Doouara TH, Rebih Z, (2002) Contribution à l'étude des caractéristiques physico-mécaniques des bétons pouzzolaniques à moyen terme », Magister, ENSET Oran.

16. Ahmaruzzaman M, (2010) A review on the utilization of fly ash, Progress in Energy and Combustion Science. 36: 327-363.

17. Ragul P, Naga Theera Hari M, Arunachelam N, Chellapandian M, (2022) An experimental study on the partial replacement of fine aggregate with perlite in cement concrete. Materials Today: Proceedings. 68: 1219-1224.

18. Tang VL, Nguyen TC, Ngo XH, Dang VP, Bulgakov B et al. (2018) Effect of natural pozzolan on strength and temperature distribution of heavyweight concrete at early ages. ESCI, MATEC Web of Conferences. 193: 1-11.

19. Celik K, Hay R, Hargis CW, Moon J, (2019) Effect of volcanic ash pozzolan or limestone replacement on hydration of Portland cement. Construction and Building Materials. 197: 803-812.

20. Yu LH, Ou H, Zhou SX, (2010) Influence of perlite admixture on pore structure of cement paste, Advanced Materials Research. 97: 552-555.

21. Brahimi S, Hamadache M, Goullieux A, Dheilly R-M, (2023) Effect of cement substitution by both perlite and pozzolan powders on the mechanical behavior and water absorption of pozzolanic mortar. Key Engineering Materials. 955: 165-170.

22. Hamadache M, Mouli M, Bouhamou N, Chaib O, Benosman AS, et al. (2016) Characterization of pozzolanic additions in the mortar for building energy efficiency. J Materials Environmental Science 7: 416-421.

23. Guenanou F, Khelafi H, Aattache A (2019) Behavior of perlite-based mortars on physicochemical characteristics, mechanical and carbonation: Case of perlite of Hammam Boughrara. Journal Building Engineering. 24: 100734.

24. NF EN 197-1 (2012) Cement-Part 1: composition, spécifications et critère de conformité pour les ciments, AFNOR.

25. EN 12620+A1 (2008) Sable normal et mortier normal. AFNOR, Paris.

26. Dif F, Mouli M, (2018) Compressive strength and corrosion evaluation of concrete containing pozzolana and perlite immersed in aggressive environments. Construction and Building Materials 179: 25-34.

27. NF EN 196-1 (2006) Détermination des résistances mécaniques, in Méthodes d'essais des ciments-Partie 1: Comité Européen de Normalisation (CEN). AFNOR, Paris, France.

28. NF EN 12390-3 (2019) Essais pour béton durci - Partie 3: résistance à la compression des éprouvettes- Juin.

29. NF ISO 15148, (2003) Détermination de coefficient d'absorption d'eau à court terme.

30. Chihaoui R, Siad H, Senhadji Y, Mouli M, Nefoussi AM, et al. (2022) Efficiency of natural pozzolan and natural perlite in controlling the alkali-silica reaction of cementitious materials. Journal Homepage Case Studies in Construction Materials. 17: e01246.

31. Chaib O, Mouli M, Hanifi M, Hamadache M, (2016) Study of the influence of natural pozzolan parameters on the strength of mortars based composite cements. Journal Materials Environmental Science. 7: 422-428.

32. Benkaddour M, Kazi Aoual F, Semcha A, (2009) Durabilité des mortiers à base de pouzzolane naturelle et de pouzzolane artificielle. Revue Nature et Technologie 1: 63-73.

33. Ghrici M, Kenai S, Meziane E-H, (2006) Mechanical and durability properties of cement mortar with Algerian natural pozzolana. Journal Materials Science. 41: 6965-6972.

34. Neville AM (2000) Propriétés des bétons. Eyrolles, Paris. ISBN 978-2-212-01320-7.