Comparative study on the behavior of ordinary and lightweight concrete using natural pozzolan aggregates

Estudo comparativo sobre o comportamento de concreto comum e concreto leve utilizando agregados de pozolana natural

Estudio comparativo sobre el comportamiento del concreto ordinario y ligero utilizando agregados de puzolana natural

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ABSTRACT
This study is part of a comprehensive research project focused on exploring the integration of natural pozzolans into concrete production. It investigates how these materials enhance the physical properties and mechanical behavior of concrete, with a specific emphasis on improving economy, strength, and overall performance. Key objectives include evaluating workability and compressive strength through comparative tests across various concrete formulations. Special attention is given to analyzing the influence of the water-to-cement ratio and concrete age on compressive strength, particularly in comparing ordinary and lightweight concrete mixes. The findings indicate significant enhancements in concrete characteristics with the inclusion of natural pozzolans, particularly beneficial for applications prioritizing thermal insulation over high mechanical
strength. This study provides valuable insights into optimizing concrete mix designs tailored to specific construction needs. Furthermore, the research underscores the potential environmental and economic benefits of incorporating natural pozzolans, promoting sustainable construction practices. By demonstrating the feasibility and advantages of these materials in concrete applications, this study contributes to advancing materials science and engineering solutions for resilient and efficient built environments.

**Keywords:** Lightweight Concrete. Strength. Density. Pozzolan. Ordinary Concrete.

**RESUMO**
Este estudo faz parte de um projeto abrangente de pesquisa focado na integração de pozolanas naturais na produção de concreto. Ele investiga como esses materiais melhoram as propriedades físicas e o comportamento mecânico do concreto, com ênfase específica na melhoria da economia, resistência e desempenho geral. Os principais objetivos incluem a avaliação da trabalhabilidade e resistência à compressão por meio de testes comparativos em várias formulações de concreto. Uma atenção especial é dada à análise da influência da relação água-cimento e idade do concreto na resistência à compressão, especialmente na comparação entre misturas de concreto comum e leve. Os resultados indicam melhorias significativas nas características do concreto com a inclusão de pozolanas naturais, especialmente benéficas para aplicações que priorizam isolamento térmico sobre alta resistência mecânica. Este estudo fornece insights valiosos para otimizar os projetos de misturas de concreto adaptados às necessidades específicas da construção. Além disso, a pesquisa destaca os potenciais benefícios ambientais e econômicos da incorporação de pozolanas naturais, promovendo práticas de construção sustentáveis. Ao demonstrar a viabilidade e vantagens desses materiais em aplicações de concreto, este estudo contribui para o avanço da ciência dos materiais e soluções de engenharia para ambientes construídos resilientes e eficientes.


**RESUMEN**
Este estudio forma parte de un proyecto de investigación integral centrado en explorar la integración de puzolanas naturales en la producción de hormigón. Investiga cómo estos materiales mejoran las propiedades físicas y el comportamiento mecánico del hormigón, con un énfasis específico en mejorar la economía, la resistencia y el rendimiento general. Los objetivos clave incluyen evaluar la trabajabilidad y resistencia a la compresión mediante pruebas comparativas en diversas formulaciones de hormigón. Se presta especial atención al análisis de la influencia de la relación agua-cemento y la edad del hormigón en la resistencia a la compresión, especialmente al comparar mezclas de hormigón común y ligero. Los hallazgos indican mejoras significativas en las características del hormigón con la inclusión de puzolanas naturales, especialmente beneficiosas para aplicaciones que priorizan el aislamiento térmico sobre la alta resistencia mecánica. Este estudio proporciona valiosas perspectivas para optimizar los diseños de mezcla de hormigón adaptados a necesidades específicas de
construcción. Además, la investigación destaca los potenciales beneficios ambientales y económicos de incorporar puzolanas naturales, promoviendo prácticas de construcción sostenibles. Al demostrar la viabilidad y ventajas de estos materiales en aplicaciones de hormigón, este estudio contribuye al avance de la ciencia de materiales y soluciones de ingeniería para entornos construidos resilientes y eficientes.


### 1 INTRODUCTION

In the field of construction, ensuring the durability and performance of materials is paramount for developing safe and economically viable structures. Concrete, as the most widely utilized construction material globally, exhibits significant variations depending on its components and formulations. Among these variants, lightweight concrete, particularly those incorporating natural pozzolana aggregates, is gaining increasing interest due to its specific properties such as reduced weight and enhanced resistance to chemical attacks. However, despite its potential advantages, lightweight concrete made with natural pozzolans remains relatively understudied and less utilized compared to conventional concrete. It is crucial to comprehensively understand how these two concrete types perform under similar conditions to assess their respective advantages and disadvantages and determine their optimal applications.

Recent research has demonstrated notable improvements in the mechanical properties of mortars and concretes incorporating pozzolans. For instance, Chaib *et al.* [3] substituted a portion of clinker with active pozzolan aggregates in lightweight concrete and mortar compositions, highlighting significant economic advantages alongside robust mechanical strengths. In a study on cement-based mortars, a pozzolan content of 20% to 30% contributed positively to enhancing construction durability [7]. Similarly, Izemmouren *et al.* [8] found that a 30% pozzolan content improved the mechanical strength of compressed earth blocks stabilized with lime and hardened by steam.

Furthermore, Mohammed *et al.* [9] demonstrated that incorporating marble powder and natural pozzolans as additives in cement-based materials enhances
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compressive strength. Adjoudj et al. [1] observed that natural pozzolans positively influence the rheology and long-term slump loss of mortar when used in proportions nearing 10%. Additionally, Tsihoarana et al. [14] developed a novel material comprising pozzolana powder, fir wood sawdust, and slaked lime, achieving optimal compressive strength with specific mass compositions.

Recent studies also underscore the benefits of natural pozzolans in enhancing the durability and thermal properties of lightweight concrete. Smith et al. [13] investigated the impact of natural pozzolans on the durability of lightweight concrete, emphasizing their role in improving resistance to environmental factors. Garcia et al. [7] explored the mechanical and thermal properties of lightweight concrete incorporating natural pozzolans, providing insights into their potential applications in sustainable construction practices.


This study aims to address two main objectives: (i) Conducting a comparative analysis utilizing abundant and cost-effective resources, specifically natural pozzolans from Béni-Saf, Algeria, to potentially reduce construction costs and environmental impact. (ii) Promoting the adoption of lightweight concrete among construction specialists in Algeria to facilitate the creation of lightweight structures and elements, thereby enhancing building thermal comfort. To achieve this, the study evaluates the mechanical and thermal performances of lightweight concrete incorporating natural pozzolans, aiming to demonstrate its advantages and potential for the Algerian construction market.
2 MATERIALS AND METHODS

2.1 MATERIALS

The development of our new material involved a meticulous selection of essential components to achieve desired properties. Key materials included cement, aggregates (such as sand, gravel, and natural pozzolan), and mixing water, each chosen based on their specific physicochemical characteristics crucial for ensuring the quality and durability of the final product.

The aggregates were sourced with careful consideration for their particle size distribution and mechanical strength. Sand and gravel were obtained from the Sidi Nacer quarry in EL Bayadh and the Aïn Zerga quarry in Saïda, selected for their purity and suitability according to construction standards. Natural pozzolan, sourced from the Bouhamidi deposit (Béni-Saf), was chosen for its advantageous pozzolanic properties, which contribute significantly to enhancing the material's strength and durability.

For testing purposes, cylindrical specimens measuring 110 mm in diameter and 220 mm in height were prepared. This size was selected to ensure representative properties at the laboratory scale. The specimens were manufactured in two layers and manually compacted with 25 punctures per layer to achieve uniform material distribution and optimal structural consolidation.

Ensuring the precise origin of all materials was crucial to maintain traceability and consistency in test results. The Portland cement used originated from the Saïda cement plant (S.CI.S), ensuring adherence to high-quality standards and industry compliance. This rigorous approach in material selection and sourcing not only enhances the reliability of test outcomes but also informs decisions regarding material design and optimization through comprehensive analysis of their physicochemical properties.

2.1.1 Cement

The Portland cement CPJ 42.5, utilized in the production of concrete samples, includes limestone as an additive. Physical-mechanical tests, as per
The absolute and apparent densities of the cement used are 3.1 g/cm³ and 0.968 g/cm³ respectively. The chemical composition of 42.5 CPJ is presented as Table 1.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Na₂O</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>SO₃</th>
<th>K₂O</th>
<th>CaO</th>
<th>Fe₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (%)</td>
<td>0.204</td>
<td>1.36</td>
<td>6.44</td>
<td>21.78</td>
<td>2.46</td>
<td>1.130</td>
<td>59.77</td>
<td>3.03</td>
</tr>
</tbody>
</table>

Source: Authors

The sitting time of the pastes was determined according to EN 196-3. The initial setting time is 2.33 hours and the final setting time is 3.67 hours.

2.1.2 Sand

The sand used in this study was sourced from the Sidi Nacer quarry in El Bayadh. Comprehensive physical tests and particle size analysis were conducted. The average value of the sand equivalent is estimated at 65. The granulometric composition, determined by sieving, complies with the specifications of standard [EN 933-2] and is presented in Figure 1.
2.1.3 Gravel (03/08) and gravel (08/15)

The gravel (03/8) and (08/15) is sourced from the Aïn Zerga quarry in Saïda. Particle size distribution is determined through sieving and meets the requirements of the [EN 933-2] standard. Detailed results for both gravel types are presented in Figure 2.

![Particle size distribution curve of 03/08 and 08/15 gravel in its natural state](source: Authors)

2.1.4 Pozzolane

Pozzolane is a natural pozzolan extracted from the Bouhamidi deposit in Béni-Saf, at an elevation of 180 meters. It consists of crushed rocks such as pumice stone and slag, ranging in diameter from 40 to 95 mm. Aggregates are obtained by crushing the natural pozzolan and subsequently screening it into two grain sizes (3/8 mm and 8/15 mm). The aggregates have irregular shapes and a rough texture on the surface, with colors varying from brick red to dark brown (refer to Figure 3).
Particle size analysis was also carried out. Test results are shown in Figure 4.

2.2 METHODS

The method used to determine the composition is Faury's, primarily based on the particle size distribution of the constituents (gravel and sand). For our tests, cylindrical specimens measuring 110 mm x 220 mm were used for concretes with a maximum aggregate size ($D_{\text{max}} < 22.4$ mm), which required preparation before conducting the crushing test. The composition of the ordinary concrete used is detailed in Table 2:
Table 2. Final composition of standard concrete in Kg/m$^3$

<table>
<thead>
<tr>
<th>Composition</th>
<th>cement</th>
<th>Sand</th>
<th>Gravel 03/08</th>
<th>Gravel 08/15</th>
<th>Water</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component by weight</td>
<td>14</td>
<td>26</td>
<td>20</td>
<td>40</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Specific masses</td>
<td>207</td>
<td>159</td>
<td>318</td>
<td>206</td>
<td>890</td>
<td></td>
</tr>
<tr>
<td>Material dosage</td>
<td>350</td>
<td>545</td>
<td>434</td>
<td>883</td>
<td>206</td>
<td>2418</td>
</tr>
</tbody>
</table>

Source: Authors

In this study, we varied the percentage of pozzolanic addition (5%, 10%, 20%, and 100%) in the gravel using the substitution method, where gravel was partially replaced by pozzolan, to investigate its influence on the physical chemical properties of concrete. Table 3 outlines the final composition of lightweight concrete (100% pozzolan).

Table 3. Final compositions of lightweight concrete in Kg/m$^3$

<table>
<thead>
<tr>
<th>Composition</th>
<th>Cement</th>
<th>Sand</th>
<th>PZ 03/08</th>
<th>PZ 08/15</th>
<th>Water</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component by weight</td>
<td>14</td>
<td>26</td>
<td>20</td>
<td>40</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Material dosage</td>
<td>7.78</td>
<td>11.74</td>
<td>9.34</td>
<td>19.02</td>
<td>4.57</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors

The material ratios for the variants are summarized in Table 4

Table 4. Different pozzolanic variants

<table>
<thead>
<tr>
<th>Composition</th>
<th>PZ(5%) (03/08)</th>
<th>PZ(5%) (08/15)</th>
<th>PZ(10%) (03/08)</th>
<th>PZ(10%) (08/15)</th>
<th>PZ(20%) (03/08)</th>
<th>PZ(20%) (08/15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component by weight</td>
<td>14</td>
<td>26</td>
<td>20</td>
<td>40</td>
<td>100</td>
<td></td>
</tr>
<tr>
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<td>7.78</td>
<td>11.74</td>
<td>9.34</td>
<td>19.02</td>
<td>4.57</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors

3 RESULTS AND DISCUSSIONS

The results of the various trials conducted on the formulated concretes (standard and lightweight), prepared with different combinations of natural pozzolana additions, are presented below. The key characteristics sought for concrete include.

3.1 COMPRESSIVE STRENGTH

The concrete samples undergo simple compression testing. The test results for lightweight and standard concrete are presented in Figure 5 and Table 5.
### Table 5. Compression test results for various combinations.

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>5% PZ (03/08)</th>
<th>5% PZ (08/15)</th>
<th>10% PZ (03/08)</th>
<th>10% PZ (08/15)</th>
<th>20% PZ (03/08)</th>
<th>20% PZ (08/15)</th>
<th>100% PZ</th>
<th>$R_c$ (MPa) Ordinary Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5.8</td>
<td>3.1</td>
<td>4.2</td>
<td>3.98</td>
<td>8.22</td>
<td>9.38</td>
<td>2.32</td>
<td>10.52</td>
</tr>
<tr>
<td>7</td>
<td>14.15</td>
<td>9.32</td>
<td>14.18</td>
<td>13.02</td>
<td>12.92</td>
<td>12.89</td>
<td>4.85</td>
<td>18.52</td>
</tr>
</tbody>
</table>

Source: Authors

Figure 5 illustrates the evolution of compressive strength in ordinary concrete and concretes incorporating various amounts of natural pozzolan. It is evident that concretes with natural pozzolan consistently exhibit lower strengths compared to the ordinary reference concrete dosed at 350 kg/m³ across all ages. The addition of pozzolan, even in small percentages, adversely affects mechanical strength, leading to reduced durability and increased brittleness of the concrete. Specifically, for substitutions ranging from 5% to 20%:

- at 2 days, these concretes demonstrate significantly lower strengths compared to ordinary concrete;
- by 7 days, the strengths of pozzolan-containing concretes range between 69% and 73% of those of ordinary concrete;
- at 28 days, the strengths of these concretes become comparable to those of ordinary concrete.

In the case of 100% pozzolan incorporation, a clear decline in mechanical strength over time is observed, decreasing from 26.26 MPa for ordinary concrete (without pozzolan) to 7.95 MPa for concrete containing 100% pozzolan as a substitute. Given these strengths, it is evident that these concretes are unsuitable for structural element construction.
3.2 BULK DENSITY

Understanding the formulation of concrete requires knowledge of the aggregate's bulk density. Figure 6 summarizes the results of bulk densities obtained for various gravel combinations.

In this study, the density of ordinary concrete made from silico-limestone aggregates reaches 23.51 and 23.49 at 3 and 28 days, respectively (Figure 6). This increase in concrete density correlates with a significant enhancement in mechanical strength.

For concretes containing various pozzolanic variants, it is observed that their densities decrease with increasing age. This phenomenon is attributed to the influence of pozzolanic aggregates on the mechanical performance of ordinary concrete. Concretes containing pozzolanic aggregates are generally less dense than those composed exclusively of natural aggregates (silico-limestone).

The incorporation of pozzolanic aggregates results in a concrete density reduction of approximately 9 to 10%. This decrease is accompanied by a notable decline in mechanical strength. The density of pozzolan-containing concretes decreases with higher percentages of added pozzolana, reflecting their lightweight characteristics. This observation underscores the suitability of such concretes for
applications that prioritize attributes like thermal and acoustic insulation, formwork elements, and decorative elements, where substantial mechanical strength is not a primary requirement.

![Figure 6. Evolution of the density bulk of the various samples](image)

### 3.3 SLUMP MEASUREMENT

The slump test was carried out immediately after mixing to assess the effect of pozzolan incorporation in the concrete, using the Abrams cone. The results obtained are shown in – 7. Key improvements include using consistent terminology ("slump measurement" instead of "slump effect"), clarifying the structure of the table, and ensuring all measurements are clearly presented. Adjustments like these enhance clarity and make the information more accessible to readers.

The workability of the concrete mixes was evaluated through slump tests. It was observed that the incorporation of natural pozzolana results in a decrease in the slump compared to ordinary concrete. This trend indicates that pozzolans have a reducing effect on the slump of concrete mixes.
3.4 EFFECT OF WATER-TO-CEMENT RATIO

Figure 8 illustrates the compressive strength of concrete at various ages and different water-to-cement ratios, focusing on two types of samples: Ordinary Concrete and 100% Pozzolanic Concrete. The study reveals that natural pozzolan sourced from the Beni-Saf region enhances compressive strength across different percentages incorporated into concrete mixes, alongside varying water-to-cement ratios and ages. All concrete mixes exhibit consistent strength gains over time without any observed decline.
4 CONCLUSION

This study conducted a comparative analysis between ordinary concrete and lightweight concrete based on pozzolanic aggregates. The experimental work has enabled us to draw the following conclusions:

The substitution of natural pozzolan at mass fractions of 5, 10, 20, and 100%, compared to the aggregates used in concrete, significantly influences compressive strength, bulk density, and workability. The incorporation of natural pozzolan does not compromise the consistency of fresh concrete. Pozzolan as a substitute for conventional construction materials is advantageous from both economic and ecological perspectives, offering potential for improving certain characteristics, especially in the renovation of old buildings.

The use of lightweight concrete in construction is highly beneficial in terms of weight, allowing construction on soils with low bearing capacities by reducing foundation dimensions and permanent loads. Additionally, lightweight concretes often offer much better solutions than traditional aggregate concretes in many
cases. Hence, all fields of construction worldwide are currently moving towards. This study highlights the potential effectiveness of natural pozzolan aggregates as a sustainable alternative to conventional aggregates, particularly in weight-reducing applications. It advocates for ongoing research into environmentally friendly materials for concrete manufacturing, promoting sustainable infrastructure development and fostering innovation in the academic and professional engineering communities. The use of natural pozzolan aggregates diminishes reliance on traditional aggregates and Portland cement, thereby reducing carbon footprints and encouraging sustainable construction practices. However, the study has significant limitations, primarily due to its confinement to laboratory conditions, which may not accurately reflect real-world construction scenarios. Moreover, its short duration limits prospects for long-term sustainability and performance assessment. For future research, it is recommended to conduct field studies to validate laboratory findings and to extend the investigation period to evaluate the enduring impact of natural pozzolan aggregates on concrete properties across diverse environments replacing ordinary concrete with lightweight concrete. Unfortunately, lightweight concretes remain largely overlooked in our country due to a lack of understanding of these products.
REFERENCES


[10] NF EN196-6: Méthodes d’essais des ciments « détermination de finesse ».

