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Eco-performant mortar with clay shale from Settat, Morocco: Thermal, mechanical, and environmental analysis

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ABSTRACT

This study investigates the use of clay shale from the Settat-Khouribga region in Morocco as a sustainable substitute for sand in mortar, targeting improvements in thermal insulation, mechanical strength, and environmental impact. Mortar samples were prepared with varying clay shale contents (5%, 15%, and 25%), combined with CPJ45 cement and a 0.5 water-to-cement ratio. These samples were rigorously tested for thermal conductivity, diffusivity, specific heat, compressive strength, and flexural strength over curing periods of 1, 7, and 28 days. The findings indicate that incorporating clay shale significantly reduces the mortar's thermal conductivity, with the 25% shale content achieving the lowest thermal conductivity of 0.6 W/m· K after 28 days, making it highly effective for insulation. However, the 15% clay shale mix emerged as the optimal balance, providing both enhanced insulation and structural performance, with compressive strength reaching 18 MPa at 28 days comparable to standard mortars. Flexural strength in the 15% mix also showed stability, suggesting suitability for structural applications. Environmentally, using clay shale decreases dependence on natural sand and lowers carbon emissions associated with mortar production. This research demonstrates that clay shale-modified mortars are a viable solution for sustainable construction, particularly in regions with readily available clay shale, supporting global efforts toward greener building practices.

Keywords: clay shale, sustainable construction, thermal conductivity, compressive strength, eco-friendly mortar, environmental impact.

INTRODUCTION

The construction industry, a fundamental component of global infrastructure development, is confronted with considerable sustainability and environmental impact challenges. As urbanization continues to accelerate, the demand for construction materials is correspondingly increasing, which is leading to the depletion of natural resources and heightened environmental concerns. While traditional building materials such as cement and sand are indispensable for the construction of durable structures, their production processes are characterized by high energy consumption and contribute significantly to greenhouse gas emissions. Consequently, the necessity for sustainable alternatives has become more urgent than ever [1].

These challenges encourage the exploration of alternative materials for sustainable construction. This study examines clay shale, a locally abundant material in the Settat-Khouribga region of Morocco, to reduce the environmental impact of the building sector.

Recent studies have increasingly focused on the development of eco-friendly construction materials, with researchers exploring various natural and industrial by-products as potential alternatives to traditional components [2]. Clay shale represents a promising material for use in sustainable building applications, given its abundance and favorable physical properties. The objective of this study is to build a more detailed understanding of the Settat-Khouribga region's clay shale deposits and their capacity to be used in mortar [3]. In response to these challenges, the exploration of alternative materials that can reduce the environmental footprint of construction activities has gained considerable attention.

Several studies have explored using alternative materials in construction to enhance sustainability and reduce environmental impact. For example, incorporating industrial by-products, such as lime sludge [4], wood ash [5], and stone slurry [6], has shown promise in partially replacing traditional materials like cement and sand. These alternatives not only help conserve natural resources but also contribute to reducing carbon emissions. Additionally, the use of recycled waste materials, such as plastics, in mortar mixes has demonstrated the potential for creating eco-friendly construction materials without significantly compromising strength and durability [7–9]. Using clay shale as a partial sand replacement creates a mortar that is both thermally and mechanically efficient, while also contributing to the conservation of natural resources and reduction of CO_2 emissions.

The Settat-Khouribga region in Morocco is rich in clay shale deposits, yet its application in the construction industry, particularly in mortar production, remains underexplored. Mortar, a key component in masonry, plays a crucial role in the structural integrity of buildings. By partially substituting sand with clay shale in mortar, it may be possible to create a more eco-friendly building material that conserves natural sand resources and enhances the structures' thermal properties, leading to improved energy efficiency [10].

The thermal performance of building materials represents a crucial aspect in reducing energy consumption, particularly in regions characterized by extreme climatic conditions. Materials with high thermal insulation properties can markedly reduce the energy expenditure required for heating and cooling buildings, thereby lowering overall energy costs and contributing to environmental sustainability. In this context, the incorporation of clay shale into mortar formulations could prove advantageous in two ways: firstly, by reducing the reliance on non-renewable sand, and secondly, by enhancing the thermal efficiency of buildings [11].

This study focuses on the development of an eco-performant mortar by incorporating clay shale as a partial sand replacement. The research is designed to assess the impact of clay shale on the mortar's mechanical and thermal properties. Mechanical properties, such as compressive and flexural strength, are critical for ensuring the structural integrity of the mortar, while thermal properties, including thermal conductivity and diffusivity, are essential for determining the energy efficiency of the material [12].

The methodology involves the preparation of mortar samples with varying proportions of clay shale – specifically 5%, 15%, and 25% – mixed with standard sand and CPJ45 cement. These samples are subjected to a series of tests to evaluate their mechanical strength and thermal performance. The study's objective is to determine the optimal mixture that balances enhanced thermal efficiency with sufficient mechanical strength, ensuring suitability for practical construction applications [13].

The significance of this research lies in its potential to contribute to global efforts to reduce the environmental impact of the construction industry [14]. By utilizing a locally abundant material like clay shale, the study not only addresses sustainability issues but also supports the development of region-specific construction practices that are both environmentally friendly and economically viable. Furthermore, the findings could have broader implications for the construction industry, offering insights into the use of alternative materials that enhance the thermal and structural performance of building materials [15].

MATERIALS AND METHODS

Materials

Samples were prepared using CPJ45 cement with clay shale proportions of 0%, 5%, 15%, and 25% and a water-to-cement ratio of 0.5. For strength testing, specimens were molded into 50 × 50 × 50 mm cubes and 40 × 40 × 160 mm prisms.

The present study has been conducted with the employment of the CPJ45 cement, supplied by Holcim and conforming to Moroccan standard NM10.1.004. CPJ45 cement comprises a minimum of 65% clinker and additional materials such as fly ash and pozzolans. The material has been selected due to the significant prevalence of utilization in Moroccan construction projects, including projects that employ reinforced concrete and projects that involve the construction of large structures. The chemical and physical properties of CPJ45 cement (Table 1) [16].

The CPJ45 cement used in this study was chosen for its high compatibility with Moroccan construction standards and its prevalent use in local projects. This type of cement, provided by Holcim, conforms to Moroccan standard NM10.1.004, ensuring that it meets both national and international quality requirements for construction applications.

Clay shale from the Settat-Khouribga region of Morocco was tested as a partial substitute for sand in the mortar. The physical properties of the compound, including specific gravity and bulk density, were examined and quantified in Table 2, River sand from the Rabat-Sale-Kenitra region was used as the control aggregate. Potable water from Rabat's Intercommunal Autonomous Water and Electricity Distribution Authority (REDAL), meeting NM 10.1.353 standards, was used for mixing [17].

Table 2 presents a comparison of the physical and chemical properties of clay shale and river sand. Clay shale exhibits a higher specific gravity and water absorption capacity, which are advantageous for improving the mortar's stability and durability. Additionally, its high SiO_2 and Al_2O_3 content makes it particularly suitable for enhancing thermal insulation and strength in construction applications. In contrast, river sand shows lower absorption and a simpler composition, underscoring its limited role in influencing the thermal and mechanical performance of mortars (Figure 1).

Preparation and conditioning of samples

Mortar samples were prepared with varying proportions of clay shale replacing sand at three specific rates: 5%, 15%, and 25% by weight (Figure 2). The mortar mix included CPJ45 cement

Table 1. Chemical and physical properties of CPJ45 cement used in this study

Property	Chemical composition (%)	Physical properties
SiO_2	21.3	Specific Gravity: 3.15
Al_2O_3	5.58	Blaine Specific Area: 300 m²/kg
Fe_2O_3	3.4	Initial Setting Time: 180 min
CaO	62	Final Setting Time: 210 min
MgO	1.85	
K_2O	2.1	
TiO_2	0.3	
SO_3	2.4	

Table 2. Physical and chemical properties of clay shale and river sand

Property	Chemical composition (%)	Physical properties
SiO_2	21.3	Specific Gravity: 3.15
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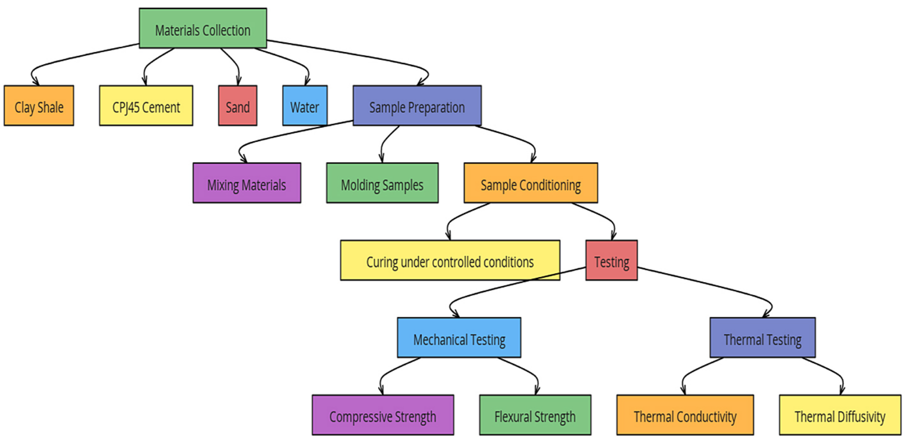

Figure 1. Diagram of the experimental methodology for studying the impact of clay shales on mortar properties

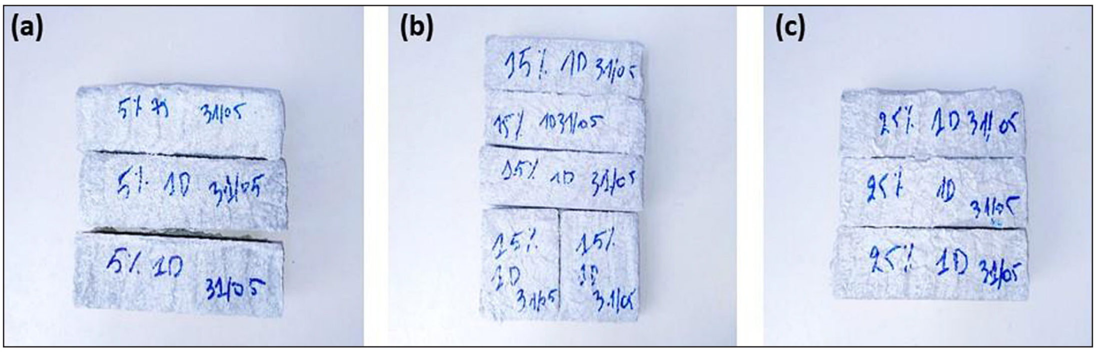

Figure 2. Experimental brick samples: traditional matrix combined with 5% (a), 15% (b), and 25% (c) of clay shale

and water, with a constant water-to-cement ratio of 0.5. The mixtures were cast into molds with dimensions of 50 × 50 × 50 mm for cubic samples and 40 × 40 × 160 mm for prismatic samples. After molding, the samples were cured at 20 ± 2 °C with 95% relative humidity for 28 days [18].

The mortar specimens produced are evaluated using a variety of techniques, including analysis of thermophysical properties such as thermal conductivity, thermal diffusivity, and heat capacity, as well as mechanical properties such as flexural strength and compressive strength.

The specimens (40 × 40 × 160 mm) were subjected to compression testing using a compression testing machine (Figure 3), with their compressive strength measured at 1, 7 and 28 days, following the NF EN 196-1 standards. Additionally, the thermal properties of the (40 × 80 × 120 mm) samples were evaluated at the same intervals using a TPS 1500 hot disc analyzer. The Transient Plane Source (TPS) method, in accordance with ISO 22007-2, was employed for its precision in analyzing thermal transport properties, providing valuable data on thermal conductivity and specific heat per unit volume.

Table 3 illustrates the proportions of mortar mixes in which sand is partially replaced by shale at different replacement levels of sand by clay shale (0%, 5%, 15%, and 25%)The control mix, identified as M0, contains no shale and is composed of 450 g of cement, 1350 g of sand, and 225 g of water.

In the other mixes (M5 to M25), the amount of sand decreases as the percentage of shale replacement increases, while the amounts of cement and water remain constant. For example, in the M5 mix (5% shale), 67.5 g of shale replaces an equivalent amount of sand, reducing the sand content to 1282.5 g. This pattern continues up to M25, where 25% of the sand is replaced by 337.5 g of shale. This analysis highlights how varying the shale content affects the mix, which is crucial for assessing the impact on the mechanical and physical properties of the mortar [7].

The Table 3 outlines the proportions of mortar mix with varying levels of sand replacement by clay shale, from 0% to 25%. In each mix (M0, M5, M10, M25), the quantities of cement (450 g) and water (225 g) remain constant, while the sand content decreases as the clay shale content increases. For instance, in mix M5 (5% shale), 67.5 g of sand is replaced by an equivalent amount of

Figure 3. Compression press used for testing schist-based mortar samples

Table 3. Proportions of mortar mix with varying clay shale content

Mix ID	Shale replacement (%)	Cement (g)	Sand (g)	Shale (g)	Water (g)
M0	0	450	1350	0	225
M5	5	450	1282.5	67.5	225
M10	10	450	1215	135	225
M25	25	450	1012.5	337.5	225

clay shale, reducing the sand content to 1282.5 g. This replacement pattern continues up to M25, where 25% of the sand is substituted by 337.5 g of clay shale. These varying proportions allow for an analysis of the impact of different clay shale contents on the mechanical and thermal properties of the mortar.

RESULTS AND DISCUSSION

Mechanical properties

Compressive strength

The compressive strength of the mortar samples was tested at 1, 7, and 28 days. The results, presented in Figure 4, indicate a clear trend: An augmentation of clay shale proportion results directly in an increase of the material's compressive strength from 0 to 15% of clay addition [19].

The graph illustrated in Figure 4 demonstrates the compressive strength (in MPa) of mortar samples over different time intervals (1, 7, and 28 days) for three levels of shale replacement: 5%, 15%, and 25%. The 0% sample follows a natural pattern of strength gain, from 3 MPa at 1 day to 18 MPa at 28 days. At 5%, there's a significant jump in compressive strength from 1 day to 7 days, with a slight increase from 7 to 28 days.15% additive shows a similar trend but achieves the highest compressive strength at 28 days (compared to other percentages), suggesting the optimal amount for improving compressive properties. And 25% additive also exhibits high strength but shows less improvement after the 7-day mark, indicating that additional additive beyond a certain point may not provide further strength benefits.

Flexural strength

The flexural strength (Figure 5) of the mortar was evaluated through a 28-day testing period, to determine the material's capacity to remain intact under bending forces.

The 0% additive sample shows a gradual increase in flexural strength over time, from 1, 21 at 1 day to 2.96 MPa at 28 days, indicating natural curing.

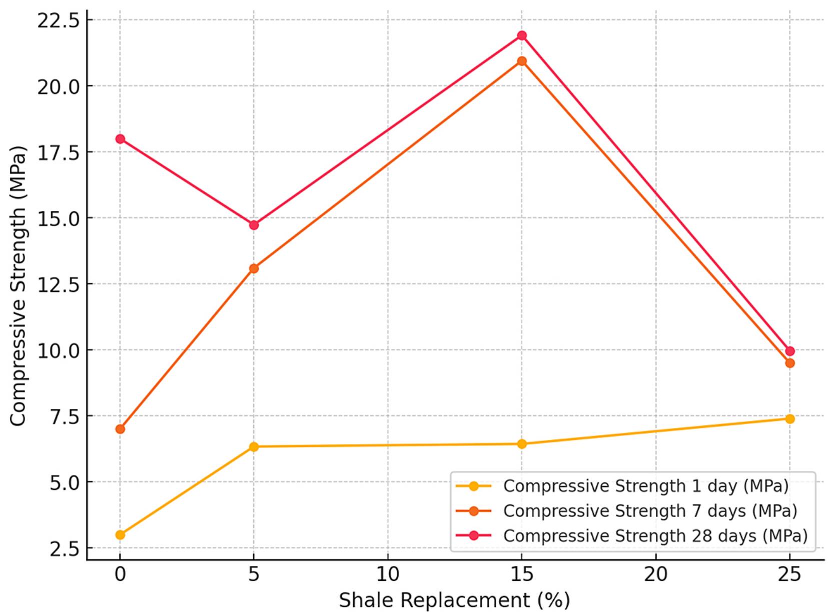

Figure 4. Development of compressive strength (MPa) of mortars with different clay shale contents over time

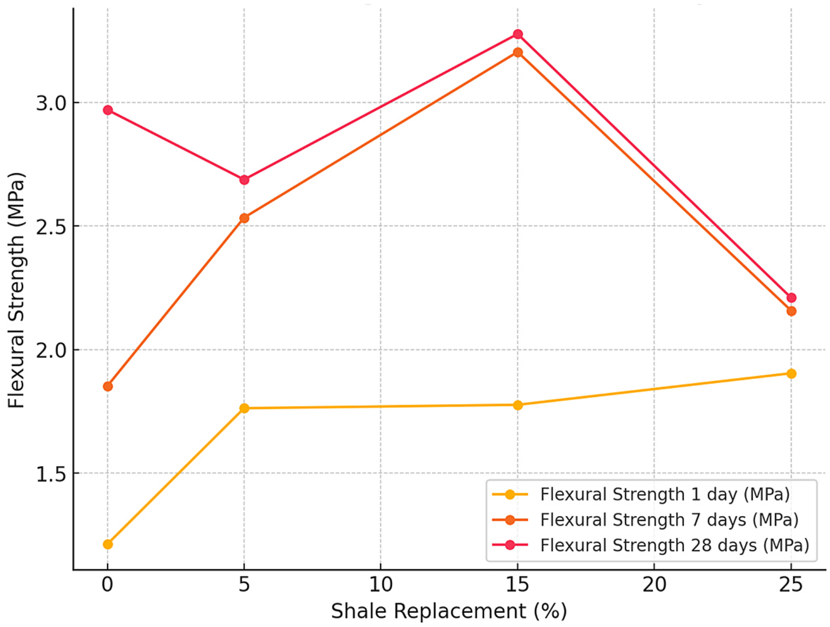

Figure 5. Evolution of mechanical strength of mortar with age and material percentage

At 5% additive, the flexural strength increases significantly between 1 and 7 days, then shows a slight reduction at 28 days. The 15% additive shows a higher initial strength than the 5% sample and continues to increase steadily up to 28 days. Reaching a higher final value compared to the lower percentages. At 25% additive, the flexural strength peaks early at 1 day and 7 days, showing a decrease by the 28-day mark, although still higher than the 0% control [20].

The analysis of flexural and compressive strength data reveals that the optimal additive percentage appears to fall between 15% and 25%, as both percentages demonstrate significant improvements compared to the 0% control sample. Interestingly, the flexural strength tends to reach its peak earlier, around the 7-day mark, in samples with higher additive content. This could be attributed to the quicker bonding and setting of the material. However, by the 28-day point, some reductions in flexural strength are observed, particularly in the 25% sample. This decrease might be due to microstructural changes or an excess of additives weakening the material structure. In contrast, compressive strength follows a more typical pattern of steady increase over time, with notable enhancements observed in the 15% and 25% samples. Among all the formulations tested, the 15% sample stands out as the most efficient in terms of both compressive and flexural properties by the 28-day mark, suggesting it may be the optimal balance for overall strength performance.

Thermal properties

Thermal conductivity

Thermal conductivity is a critical parameter for energy-efficient building materials. The results, shown in Figure 6, indicate that the inclusion of clay shale significantly reduces the thermal conductivity of the mortar, particularly at higher replacement levels [21].

Figure 7 shows the thermal conductivity of mortar samples with different levels of shale replacement (5%, 15%, and 25%) over time (1, 7 and 28 days). For the 0% additive, thermal conductivity starts at 1 W/m·K at 1 day and gradually decreases to 0.8 W/m·K at 28 days, indicating a natural reduction as the material cures. The 5% additive shows a decrease in conductivity to 0.9 W/m·K after 1 day and stabilizes at 0.76 W/m·K at 28 days. For the 15% additive, conductivity decreases further to 0.73 W/m·K by 28 days.

The 25% additive has the lowest thermal conductivity at 0.6 W/m·K at 28 days, showing that more additives significantly reduce the material's ability to conduct heat [22].

Thermal diffusivity and capacity

Thermal diffusivity (Figure 7) were measured to provide a comprehensive understanding of the material's thermal behavior. The results, illustrated in Figure 8, suggest that while the diffusivity decreases with increasing shale content,

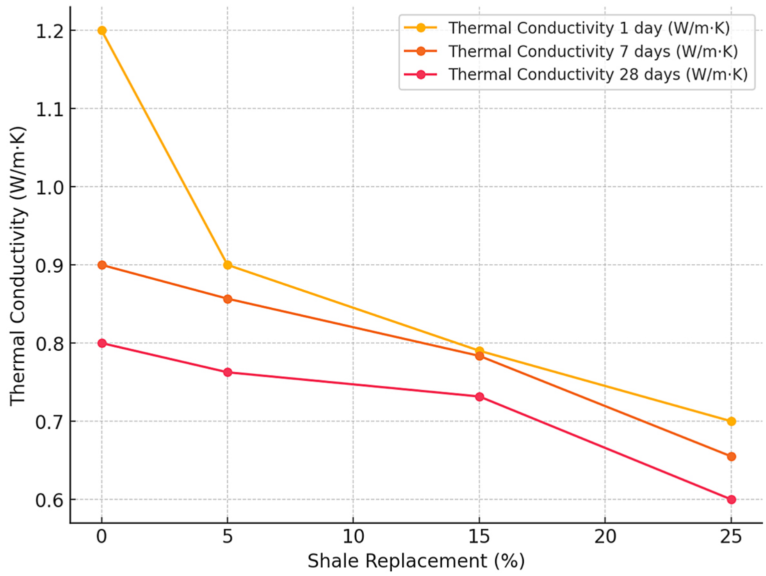

Figure 6. Evolution of thermal conductivity of mortar with shale replacement percentage at 3, 7 and 28 days

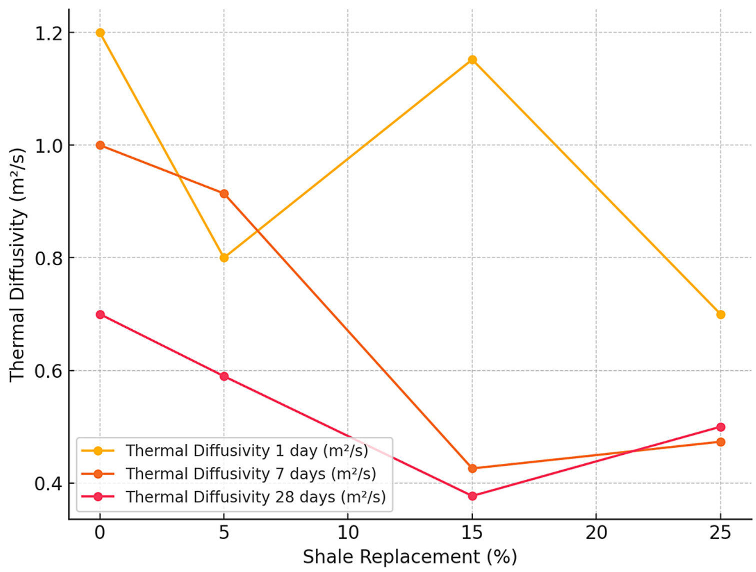

Figure 7. Evolution of thermal diffusivity of mortar with shale replacement percentage at 1, 7 and 28 days

the thermal capacity remains relatively constant [23]. The 0% additive sample starts with 1.2 m^2/s diffusivity at 1 day and decreases slightly to 0.7 m^2/s by 28 days. The 5% additive sample follows a similar trend, with an initial value of 0.8 m^2/s at 1 day and decreasing to 0.58 m^2/s at 28 days. At 15% additive sample shows more variability, starting at 1,15 m^2/s and ending at 0.37 m^2/s at 28 days, indicating that thermal diffusivity drops significantly with more additives. The 25% additive sample also shows reduced diffusivity by 28 days, stabilizing at 0.5 m^2/s [24, 25]. Figure 8 illustrate the evolution of the specific heat capacity over ages. For the 0% sample, the specific heat starts at 1 J/kg·K at 1 day and drops to 1.14 J/kg·K at 28 days.5% shows slightly increased specific heat over time, reaching 1.29 J/kg·K by 28 days. For the 15% additive, the specific heat increases further to 1.940172 J/kg·K at 28 days, suggesting improved heat storage capacity with more additives. The 25% additive sample remains stable at 1.2 J/kg·K after 28 days [26].

The thermal properties of the material show significant changes with increasing additive content, offering potential advantages for various thermal management applications. Thermal conductivity exhibits a clear downward trend as the percentage of additive increases, with the 25%

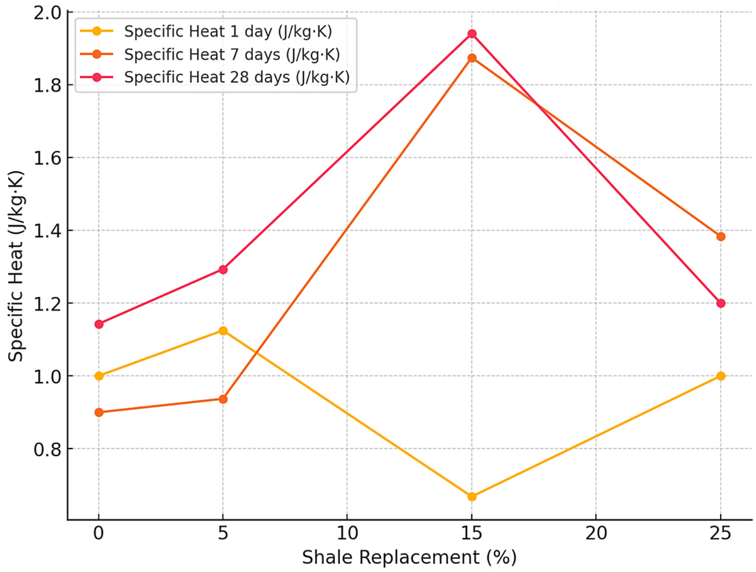

Figure 8. Evolution of specific heat (MJ/m³·K) over time (days) for three different composite percentages at 3, 7 and 28 days

additive sample demonstrating the lowest conductivity. This reduction in conductivity enhances the material's insulating properties, making higher additive content samples more effective for applications requiring thermal isolation. Thermal diffusivity follows a similar pattern, decreasing as more additives are introduced. The lower diffusivity values indicate that heat propagates more slowly through the material, which can be beneficial in maintaining temperature gradients in specific scenarios. Interestingly, the specific heat of the material tends to increase with higher additive content, with the 15% sample showing a particularly notable rise. This increased specific heat suggests an enhanced capacity for heat storage, which could be advantageous in applications where heat retention is desirable. Together, these thermal property changes indicate that the addition of the material not only improves insulation performance but also enhances the material's ability to store and gradually release heat, opening up possibilities for its use in energy-efficient building materials or thermal energy storage systems (Figures 9 and 10) [27, 28]. The comparative analysis across those results reveals that the additive percentage significantly influences the material's performance across various metrics. In terms of mechanical properties, the 15% additive concentration emerges as the optimal

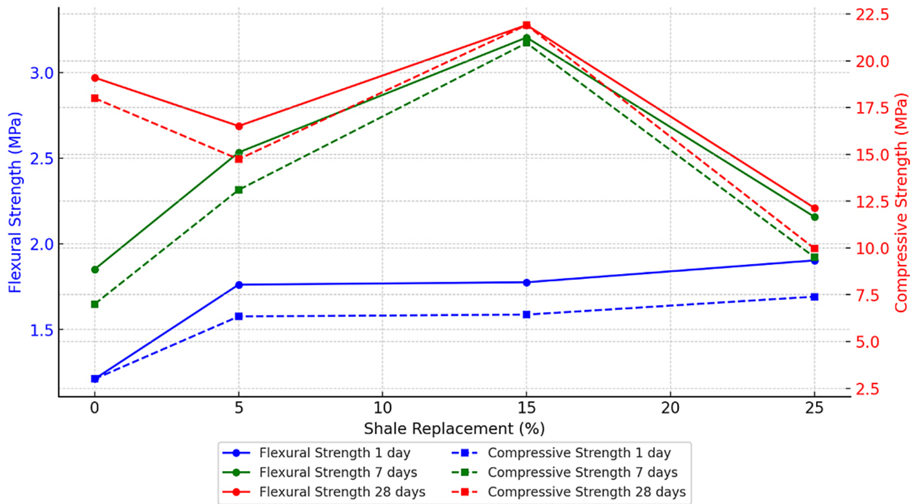

Figure 9. Comparative graph illustrating the evolution of flexural and compressive strength for different shale replacement percentages (0%, 5%, 15%, 25%) over 1, 7, and 28 days

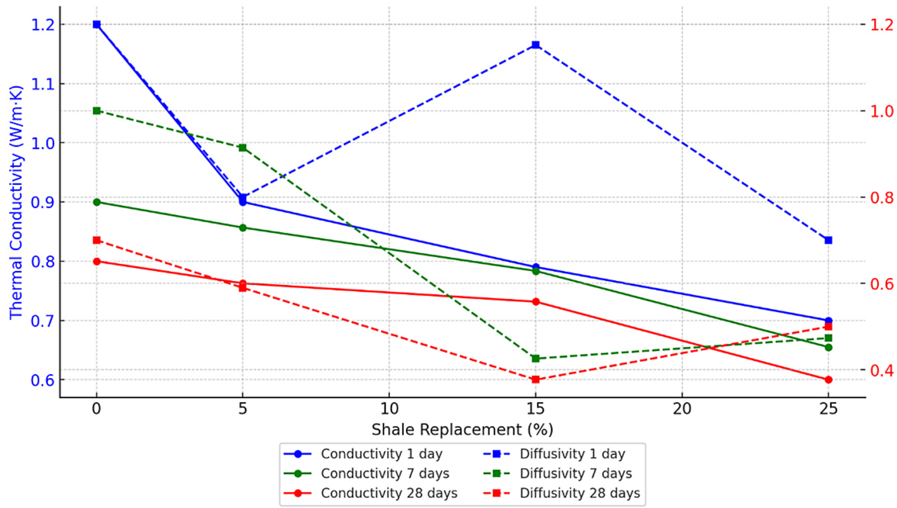

Figure 10. Comparative graph showing the evolution of thermal conductivity and diffusivity for different shale replacement percentages (0%, 5%, 15%, 25%) over 1, 7, and 28 days

choice, providing the best balance between flexural and compressive strength. While the 25% additive maximizes compressive strength, it shows less improvement in flexural strength compared to the 15% mixture. Regarding thermal properties, increasing the additive percentage generally enhances the material's insulation capabilities by lowering thermal conductivity and improves heat storage capacity by raising specific heat, with these effects being particularly pronounced at 15% and 25% concentrations. However, it's worth noting that thermal diffusivity decreases with higher additive content, indicating slower heat transfer through the material. When considering the optimal additive level, the 15% concentration stands out as the ideal choice if a balance between mechanical strength and thermal performance (especially heat storage) is required. Conversely, for applications prioritizing high compressive strength and superior thermal insulation, the 25% additive concentration proves more suitable. In conclusion, while the 15% additive strikes the best overall balance between mechanical performance and thermal properties, the 25% additive is preferable for maximizing compressive strength and insulation capabilities, highlighting the importance of tailoring the additive concentration to specific application requirements [29].

ENVIRONMENTAL IMPACT

The environmental benefits of using clay shale are twofold: it reduces the need for sand, a finite natural resource, and lowers the overall carbon footprint of the construction material. By utilizing a locally available material that would otherwise be considered waste, this approach aligns with the principles of sustainable development and resource conservation [30].

In Figure 11, the four distinct graphs explore the environmental and material impacts of increasing the percentage of clay shale. The reduction in sand extraction (top left) significantly improves with a higher percentage of shale, reducing dependency on natural resources like sand. Similarly, CO_2 emissions (top right) decrease as the shale content increases, highlighting the environmental benefit of using more shale in the mortar mix [31].

The provided graphs illustrate the impact of increasing the percentage of clay shale in mortar on several properties and environmental indicators. In Figure 12, the radar chart shows how the durability of mortar varies with shale percentages of 5%, 15%, and 25%. It is observed that thermal efficiency improves as the percentage of shale increases, reaching its peak at 25%. However, mechanical strength and longevity are highest with 5% shale and decrease as the shale content increases [32].

DISCUSSION

The comparison of the results from this study with those from similar research reveals both consistencies and areas of divergence. While previous studies have consistently highlighted the

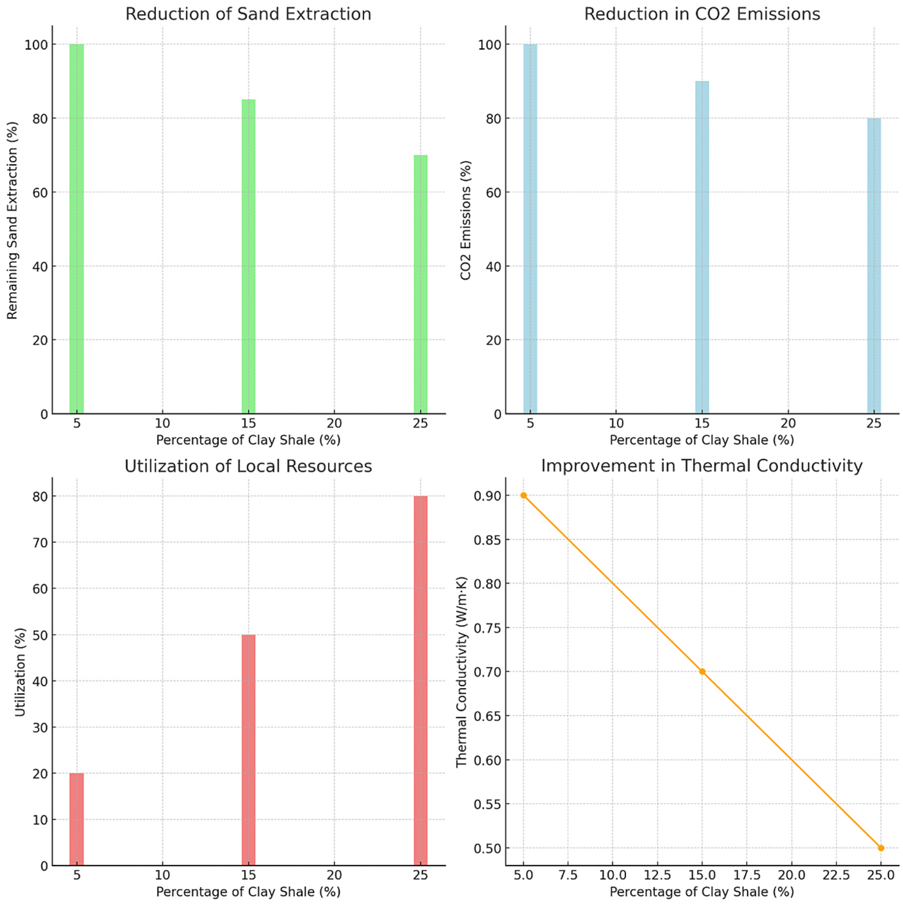

Figure 11. Environmental and material impacts of clay shale in mortar

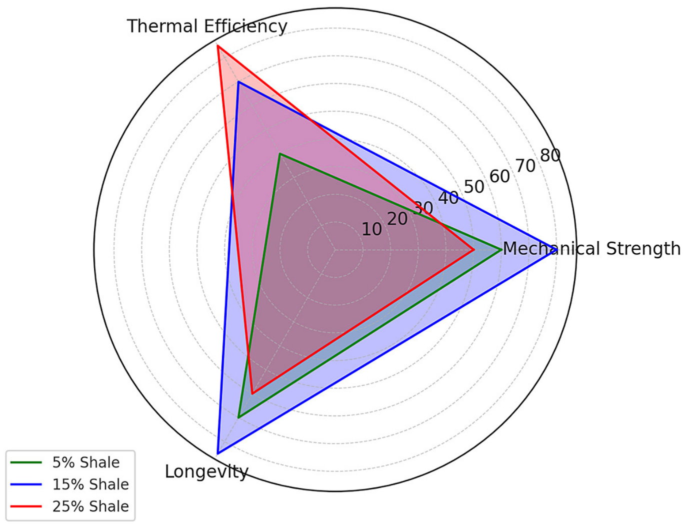

Figure 12. Durability characteristics of mortar with varying shale percentages (5%, 15%, and 25%), highlighting thermal efficiency, mechanical strength, and longevity

thermal efficiency improvements associated with clay-based mortars, this study provides specific insights into the characteristics of clay shale from the Settat-Khouribga region. The findings align with existing literature, particularly regarding the reduction of thermal conductivity with increased clay content, yet this study uniquely underscores the challenges related to maintaining mechanical strength, emphasizing the need for further optimization to balance these performance criteria effectively, Notably, the 25% shale replacement, although initially promising due to its enhanced thermal conductivity, fails to sustain adequate mechanical and compressive strength, indicating potential structural limitations at higher shale content levels.

Conversely, the 5% shale replacement, despite showing higher initial thermal diffusivity, does not offer the long-term strength and stability observed with the 15% replacement [33]. Thus, optimizing the mix to achieve both thermal benefits and mechanical integrity is essential for practical applications. The significance of compressive strength and durability in construction materials cannot be overstated. Although the incorporation of clay shale improves the thermal properties of the mortar, it simultaneously leads to a reduction in compressive strength, particularly at higher shale contents. This reduction suggests that while clay shale mortar holds considerable promise for enhancing thermal efficiency and sustainability, it requires further refinement to meet the stringent mechanical standards required for construction materials [34].

In conclusion, the 15% shale replacement emerges as the optimal blend for applications requiring both durability and thermal stability, offering the best balance between strength and thermal performance as evidenced across various parameters, including compressive strength, thermal conductivity, mechanical strength, and thermal diffusivity. The specific heat data also indicate that the 15% composition stabilizes better over time compared to higher or lower shale contents, making it the most suitable choice for maintaining consistent thermal properties as the material cures [35].

In conclusion, the 15% shale replacement emerges as the optimal mix for applications requiring a durable and thermally stable mortar, offering the best balance of strength and thermal performance as evidenced across the figures discussed: compressive strength (Figure 4), thermal conductivity (Figure 5), mechanical strength (Figure 6), and thermal diffusivity (Figure 7). This suggests that the 15% shale replacement is the most suitable choice for enhancing mortar properties in both early and later stages of curing.

The charts show that the specific heat of the composite material varies based on the composition percentage (5%, 15%, 25%) and the curing age (1 day, 7 days, 28 days). On day 1, the material with 15% composition exhibits the highest specific heat at 7.77 $MJ/m^3·K$, while the 25% and 5% compositions display 3.51 $MJ/m^3·K$ and 0.29 $MJ/m^3·K$, respectively. After 7 days, the specific heat decreases significantly for all compositions, with a notable drop to 2.15 $MJ/m^3·K$ for the 15% composition. By 28 days, the values stabilize, with the 15% composition reaching 2.26 $MJ/m^3·K$, while the 25% and 5% compositions stabilize at 1.94 $MJ/m^3·K$ and 1.06 $MJ/m^3·K$, respectively. These results indicate an initial sharp decrease in specific heat over time, particularly for the 15% composition, before the values stabilize as the material ages [36]. When compared to the findings of Joshaghani et al. (2018), who explored the effects of environmental conditions on the mechanical and microstructural properties of cement mortars, this study similarly highlights challenges in maintaining mechanical integrity with clay shale inclusion. Joshaghani et al. emphasized the importance of controlled environmental conditions in improving mortar durability, a factor that is also relevant to the current study's outcomes. The observed reduction in mechanical strength at higher shale content underscores the necessity for additional research to ensure that clay shale-enhanced mortars achieve the required durability and structural performance across various environmental conditions, consistent with the durability emphasis in Joshaghani's research [37].

Furthermore, the study that the use of local resources, such as clay shale, increases with higher shale content, promoting more sustainable material sourcing. As the shale percentage rises, thermal conductivity decreases, indicating that the mortar becomes a more effective thermal insulator. These results collectively suggest that increasing the clay shale content in mortar offers significant environmental advantages, although care must be taken to mitigate potential compromises in mechanical properties [38].

CONCLUSIONS

The incorporation of clay shale into mortar formulations offers a promising pathway for enhancing both the thermal efficiency and environmental sustainability of construction materials. While the addition of clay shale does result in a reduction in compressive strength, this drawback is offset by a significant improvement in thermal insulation properties. Mortars containing 15% clay shale by weight have been identified as achieving an optimal balance between mechanical strength and thermal performance, making them a viable option for practical applications.

However, further research is necessary to assess the long-term durability of clay shale-enhanced mortars under diverse environmental conditions and to refine the mix proportions for optimal mechanical and thermal properties. Additionally, exploring the scalability of this technology for industrial production is crucial, particularly in regions with abundant clay shale resources. Such research could pave the way for widespread adoption, contributing to localized, sustainable construction practices that leverage the specific characteristics of regional materials.

In conclusion, while the current findings are promising, future studies should focus on the long-term performance and scalability of clay shale-enhanced mortars, with an emphasis on tailoring formulations to the unique environmental and material conditions of different geographic regions. This approach has the potential to significantly advance sustainable construction practices globally.

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