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Research Article

Durability And Thermal Properties of Cement Mortar Containing Algerian Bentonite

Hadja Kawthar[1*], Bouksani Omar[2], Khelifa Kerfah Ilyas[3], Benhadji Maissen[4], Kharchi Fattoum[5], Abba Fatiha[6]

[1]Renewable Energy and Materials Laboratory (LERM), Department of Mechanical Engineering, Faculty of Technology, University Dr Yahia Fares, Medea, Algeria
Built Environment Research Laboratory (LBE), Faculty of Civil Engineering, University of Sciences and Technology Houari Boumediene, Bab-Ezzouar/Algiers, Algeria
* **Corresponding Author Email:** hadja.kawthar@univ-medea.dz - **ORCID:** 0000-0002-5247-7750

[2]Built Environment Research Laboratory (LBE), Faculty of Civil Engineering, University of Sciences and Technology Houari Boumediene, Bab-Ezzouar/Algiers, Algeria
Department of Civil Engineering, Faculty of Technology, University Yahia Fares, Medea, Algeria
Email: omar2@gmail.com - **ORCID:** 0000-0002-5247-7650

[3]Built Environment Research Laboratory (LBE), Faculty of Civil Engineering, University of Sciences and Technology Houari Boumediene, Bab-Ezzouar/Algiers, Algeria
Email: ilyas2@gmail.com - **ORCID:** 0000-0002-5247-7550

[4]Built Environment Research Laboratory (LBE), Faculty of Civil Engineering, University of Sciences and Technology Houari Boumediene, Bab-Ezzouar/Algiers, Algeria
Department of Architecture, University Saad Dahlab of Blida, Blida, Algeria
Email: maissen2@gmail.com - **ORCID:** 0000-0002-5247-7450

[5]Built Environment Research Laboratory (LBE), Faculty of Civil Engineering, University of Sciences and Technology Houari Boumediene, Bab-Ezzouar/Algiers, Algeria
Email: fattoum2@gmail.com - **ORCID:** 0000-0002-5247-7350

[5]Department of Civil Engineering, Faculty of Technology, University Hassiba ben bouali, Chlef, Algeria
Email: fatiha2@gmail.com - **ORCID:** 0000-0002-5247-7250

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Abstract:

Cement industry generates a serious problem for the environment. Its production, through the calcination of limestone rocks and the energy used, releases a significant amount of carbon dioxide, contributing to the greenhouse effect. Finding solutions to reduce the quantity of cement necessary for the manufacture of mortar can minimize energy consumption, reduce pollution and thus preserve the environment. The aim of this experimental work was to partially replace the cement with bentonite in mortars at varying percentages of 0%, 5%, 10%, 15%, 20%, 25%, and 30%. The effects of bentonite on mechanical strengths, such as compressive and flexural strengths, as well as on thermal performance by assessing the thermal conductivity coefficient were investigated. The experimental results showed that the partial replacement of cement with bentonite significantly improved the thermal insulation of mortars, since the thermal conductivity decreased from 1.59 to 1.29w/mK. However, the mechanical strengths decreased slightly as the bentonite content increased until 15% replacement. Beyond 15% replacement of cement with bentonite, the compressive and flexural strengths decrease abruptly. Finally, the durability of the mortar with bentonite is critical since water absorption increases.

1. Introduction

Cement industry generates a serious problem for the environment. It releases too much carbon dioxide, contributing to the greenhouse effects. Using bentonite as a partial cement replacement can help mitigate these problems.

Several studies have investigated the effect of bentonite on the mechanical properties of mortar and concrete. Some researchers have indicated that the mechanical strength of raw clay bentonite concrete decreases during the early ages (up to 28 days) and increases at later ages. This strength evolution was observed both when bentonite was used as a cement replacement [1-4] or as a cement addition [5-7] to mortar or concrete mixtures. Other authors found an increase in compressive strength when the bentonite replaced 30% cement [5, 8, 9].
However, few studies have been carried out on the behavior of bentonite concrete or mortar under various aggressive chemical environments (sulfate, acid and Basic). Many of these researchers found that the incorporation of bentonite improved the resistance of concrete to sulfate and acid environments. Memon et al. [2] reported that the optimum resistance to Hydrochloric and Sulfate acid attacks was obtained with 21% bentonite. Ahmad et al. [1] found that mortars with 20% bentonite showed the best resistance to sodium sulfate solution (Na2SO4). However, Mirza et al. [10] indicated that 30% bentonite improved resistance to magnesium sulfate (MgSO4) solutions.Sreenivasa et al. [11] found that 15% bentonite improved the behavior of concrete under a hydrochloric acid attack. However, in basic environments, the use of bentonite in concrete decreased its chemical resistance. This work aims to investigate the effect of partial replacement of cement with bentonite on mechanical strengths, thermal conductivity and durability against acid attack solutions and water absorption.

2. Methods

2.1 Materials Used

Cement: The cement used is portland cement type CEM I 42.5. The physico-chemical characteristics are given in Table 1.
Fine aggregate : The fine aggregate used is a dune sand with maximum size of 0/5 mm from a quarry located in Hassi bahbah region (Algeria).The physical characteristics of the sand are listed in Table 2.
Water: Distilled water was used to prepared mortars.
Bentonite: raw bentonite (98% montmorillonite) obtained from the Algerian northwest part near Maghnia city (Figure 1). The bentonite was heated at 105 °C for two hours, and it was sieved to get 80 µm particle size (Figure 2).
Acid Solutions: Hydrochloric acid (HCL) and sulfuric acid (H_2SO_4) solutions with a concentration of 5% were prepared in plastic boxes, to investigate the acid resistance.

Table 1. *Chemical composition and physical characteristics of cement*

Composition	Cement (CEM I 42.5 R)	Bentonite
SiO_2	21.10	62.30
CaO	63.7	1.5
Al_2O_3	4.72	15.25
Fe_2O_3	3.45	2.10
MgO	2.30	2.70
Na_2O	0.4	2.15
SO_3	2.03	--
K_2O	0.40	0.60
TiO_2		0.18
Loss of ignition	1.9	6.9
Blaine specific (cm^2/g)	4100	4445
Specific gravity (Kg/m^3)	3.1	2.4
Retained 75μm		4.6

Table 2. *Physical characteristics of dune sand*

Characteristics	Dune sand
Bulk density (kg/m^3)	1420
Specific gravity (kg/m^3)	2600
Fineness modulus	1.1
Sand equivalent (%)	62
Water absorption capacity (%)	0.45

Figure 1. *Raw Bentonite*

2.2 Formulation

Seven different mortar mixtures (Table 3) were used to investigate the thermal conductivity, mechanical strength, water absorption by capillary and total immersion, and resistance to acid solutions. These include one control mortar mixture prepared without bentonite and the remaining six mixtures were prepared by replacing different percentages (5, 10, 15, 20, 25 and 30%) of cement with bentonite. All of these mortars were made with a cement + Bentonite to sand ratio of 1:3 by mass.

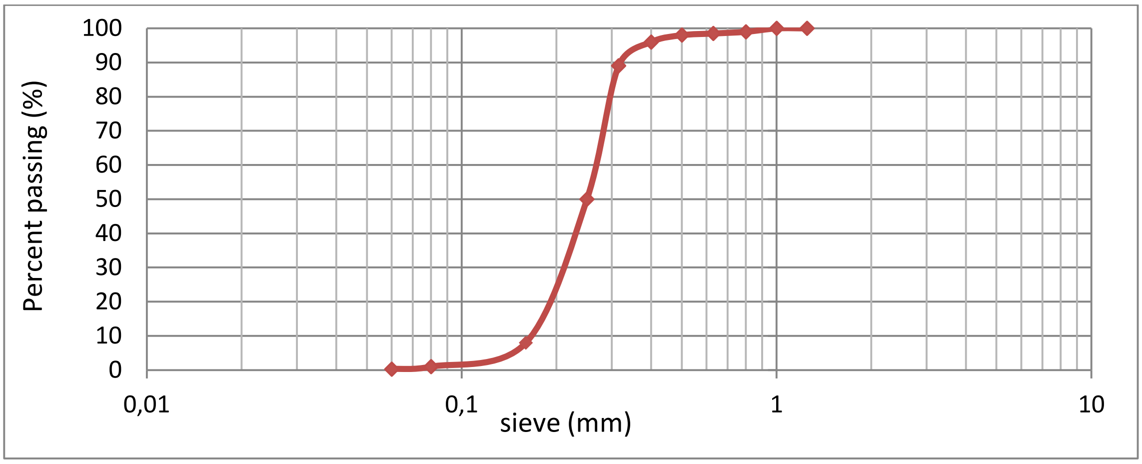

Figure 2. *Particle size distribution curve of sand*

For control mortar, the water-to-cement ratio was 0.5. While, for mortars containing bentonite, the Water-to-Binder (Cement+Bentonite) ratio content was adjusted to achieve equivalent workability to that measured of the control mortar. Table 3 summarizes the composition of the control mortar and the mortars containing bentonite.

2.3 Mix preparation

The procedure for mixing the control mortar was performed according to BS EN 196-1 standards [12]. While the mixing of mortars containing bentonite is as follows: First, cement and bentonite were dry mixed for 2 minutes at low speed. Then, the entire quantity of sand was added gradually over a 1 minute period. Once the dry blend became homogeneous, water was added gradually until the mixture became pasty. At the end, the mortars were cast in 4x4x16 cm steel molds for 24 hours.
After demolding, specimen mortars were divided into four groups. One group was cured in water at 23 ± 2 °C to assess the evolution of compressive and flexural strength at 7, 14, 21, 28, 56 and 90 days of curing. The second group was first cured for 28 days and was used to assess the capillary and total immersion water absorption tests. The third was used to investigate the thermal conductivity at 90 days. While the fourth group was first cured for 28 days and then immersed for 90 days in 5% hydrochloric acid (HCL) and sulfuric acid (H_2SO_4) solutions.

Figure 3. *Hydrochloric acid (HCL) and sulfuric acid (H_2SO_4)*

Table 3.*Component dosages for selected mixtures*

Designation	Bentonite Replacement (%)	Materials (g)			W/C
		Bentonite	Cement	Sand	
BT 0	0	0	450	1350	0.5
BT 5	5	22.5	427.5		0.53
BT 10	10	45	405		0.55
BT 15	15	67.5	382.5		0.57
BT 20	20	90	360		0.58
BT 25	25	112.5	337.5		0.59
BT 30	30	135	315		0.68

2.4 Testing

2.4.1 Flexural and Compressive strength

The mechanical strengths of mortars were evaluated by measuring the flexural and compressive strengths according toBS EN 196-1 standards [12]. Flexural strength was determined usinga three-point bendingtest on 4×4×16 cm mortar prisms, as shown in Figure 4a. The compressive test(Figure 4b) wasconductedon the halves of a 4x4x16 cm mortar prism that were previously broken in flexural.

2.4.2 Capillary water absorptiontest

Capillary water absorptionor sorptivity test was performed according to BS EN 13057 standards [13].At 28 days of curing, prisms with dimensions of 4x4x16 cm were oven-dried at 105°C until their weight stabilized. To ensure uniaxial water absorption of the prisms, allsides except the one touching the water were sealed with epoxy resin.

After that, the prismswere placed in the water (Figure 2) with a depth of immersion of about 4 $\pm$ 1 mm.

The water absorption mass was measured regularly every 5 minutes until 90 minutes.Theprisms were first wiped to remove any excess water from the suction surface and then quickly weighed (±0.01 g).The capillary water absorption is obtainedby using the following equation:

$$Abs_{capil} = \frac{\Delta M}{A} \cdot \frac{1}{\sqrt{t}} \qquad (1)$$

Where ΔM: mass of water absorbed at time t (g), A: exposed area of the specimen (cm^2) and t : elapsed time (min).

2.4.3 Water absorption by total immersion test

Water absorption by immersion was tested at 28 days according to ASTM C642-97 standards [14].In this test, three specimens from each percentage of bentonite with dimensions of 4×4×16 cm were first dried in an oven at 105°C for 24 hours. After oven drying, the specimens were left to cool at room temperature and then weighed (Md) to give the oven dry mass. Thereafter, the specimens were immersed in water at 25°C for 24 hours. After immersion, the specimens were removed from the water, wiped with a damp cloth, and their mass after immersion in water was weighed again (Mw). The water absorption by immersion isgiven by the formula:

$$Abs_{immer}(\%) = \frac{M_w - M_d}{M_d}.100 \qquad (2)$$

2.4.4 Thermal Conductivity test

The thermal conductivity of mortars wasdeterminedby the hot-wire (parallel) method according to EN-993-15 standards [15].The measurement was carried out with a CT-Meter deviceequipped with asensor wire for solid materials (Figure 6).

At 28 days, the specimens consisted of two mortar prisms with identical dimensions (4×4×16 cm) and the same formulation.Before performing the test, the specimenswere placed in a drying oven at 60°C for 24 hours. To measure the thermal conductivity, a hot-wire sensorwas inserted between the two mortar prisms.

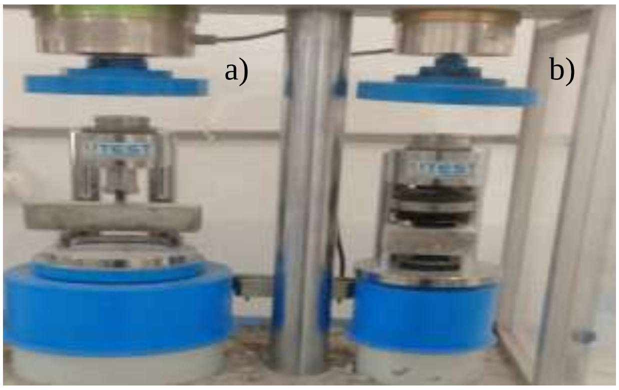

Figure 4. *Flexural strength and Compressive strength devices for mortar*

Figure 5. *Water absorption by capillary test*

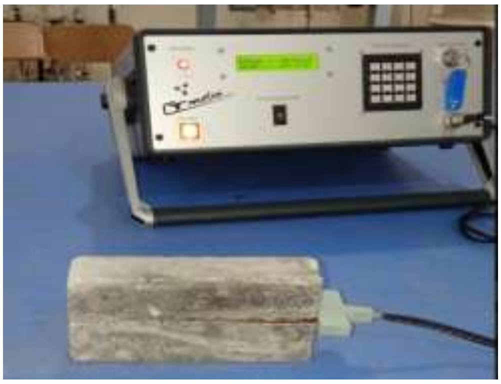

Figure 6. *Device of Thermal conductivity-meter*

3. Results

3.1 Effect of Bentonite on Compressive Strength

Figure 7 and 8 illustrates the results of the compressive and flexural strength at the ages of 7, 14, 21, 28, 56 and 90 days of curing for the mortars containing 0, 5, 10, 15, 20, 25 and 30% bentonite as a partial replacement of cement. The compressive and flexural strengths of all mortars bentonite increase gradually with the curing age.

At all ages, the highest compressive and flexural strengths were observed in mortars without bentonite. Thus, mortars containing bentonite have lower mechanical strengths than the control mortar. For example, at 28 days, the compressive strength of 0, 5, 10, 15, 20, 25 and 30% bentonite at 28 days are 39, 36, 33, 30, 26, 21 and 17 MPa, respectively. Also, the flexural strength of 0, 5, 10, 15, 20, 25 and 30% bentonite at 28 days are 3.9, 3.6, 3.3, 3.0, 2.6, 2.1 and 17 MPa.

The compressive strength decreased progressively as the content of bentonite increased until 15% replacement. However, beyond 15% of bentonite, the mechanical strengths decrease abruptly.This drop in strengths may be related to the bentonite, which can only act as a filler in the mortar. As a result, when the replacement percentage of bentonite increased, the amount of cement decreased. Thus, less cement significate less of chemical reactions, which leads to a lowmechanical strengths.The same results were shown by Mirza et al. [4], whose find a decreasing in strength while the bentonite content increases.

3.2 Effect of bentonite on capillary water absorption

The water absorption by capillary of mortars containing bentonite is presented in Figure 9. It can be seen that the water absorption increases gradually as the amount of bentonite increases. It is

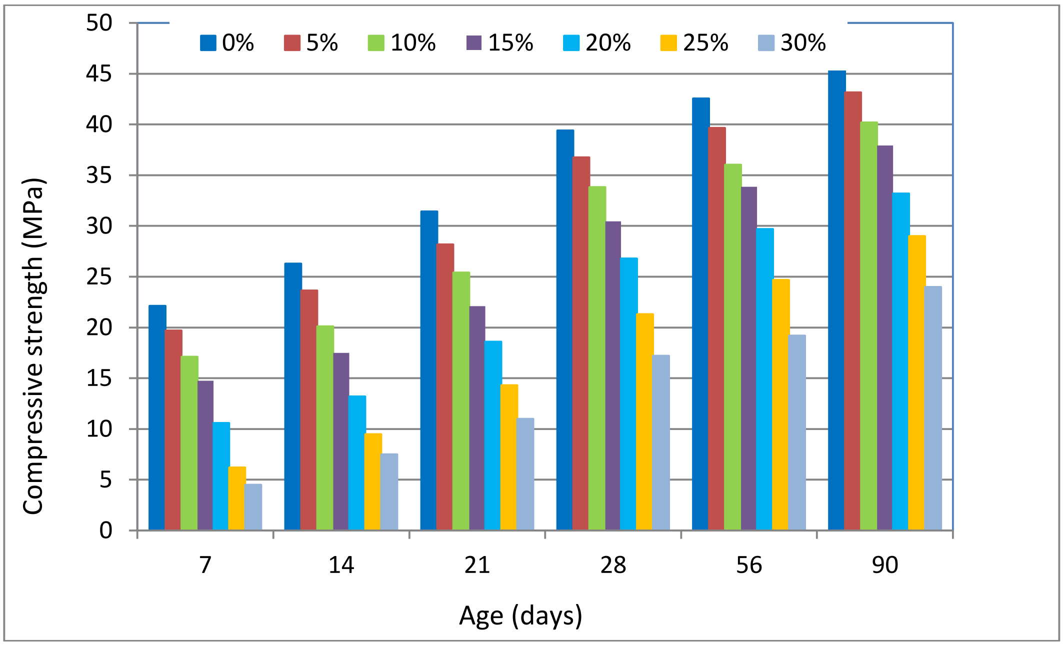

Figure 7. *Influence of Bentonite content on compressive strength*

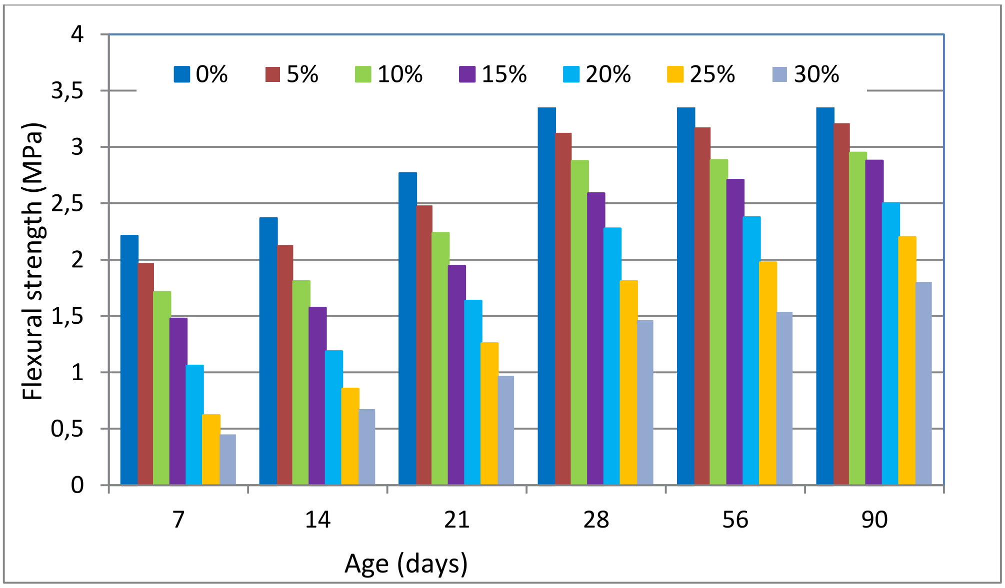

Figure 8. *Influence of Bentonite content on flexural strength*

believed that the high water absorption in mortars containing up to 30% bentonite is due to a high absorptivity of Bentonite which is the filler in the mortar.

3.3 Effect of bentonite on water absorption by immersion

The water absorption by immersion in water of mortars containing bentonite was summarized in Figure 10. It can be seen that bentonite mortar absorb more water than the control mortar without bentonite. Also, the water absorption increases gradually as the amount of bentonite increases. This might be attributed to a high absorptivity of Bentonite, which is the filler in the mortar.
This is a result of a high of porosity due to a high water to cement ratio, which also creates a poor adhesion between the bentonite particle aggregate surface and binder paste.

3.4 Effect of bentonite on Acid resistance

The behavior of mortars immersed in acid solutions has been studied by measuring the mass and compressive strengthlosses. It was found that the incorporation of bentonite instead of cement improves the performance under both $H_2SO_4$and HCl acid solutions.Figure 11 shows the mass loss of the mortars after 90 days of immersion in aggressive solutions.Formortars immersed in5% $H_2SO_4$and HCL solutions, it was observed that the incorporation of bentonite results a less loss of masscompared to mortar without bentonite. Meanwhile, mass loss in $H_2SO_4$are largest than those immersed in 5%HCL solution.This can be explained by the ability of bentonite to absorb the acid and to the low cement content means less lime is available to be attacked by the acid.

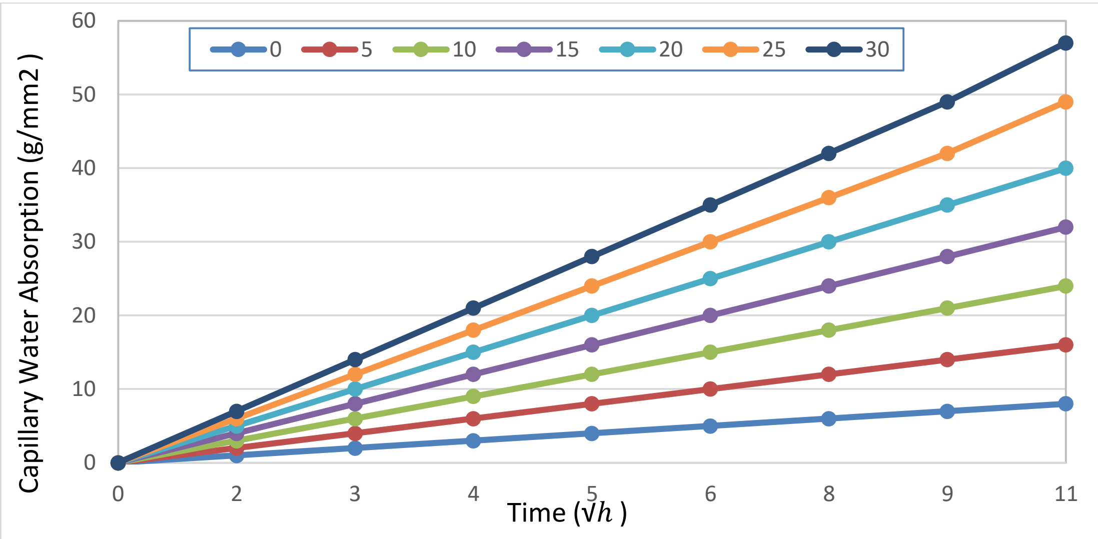

Figure 9. *Capillary water absorption of mortar containing bentonite at 28 and 90 days*

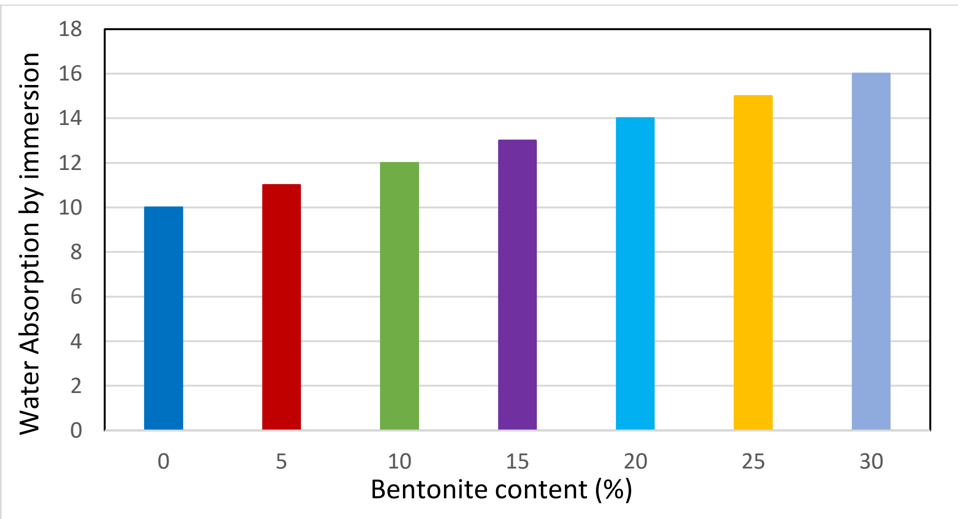

Figure 10. *Water absorption by immersion of mortar containing bentonite at 90 days*

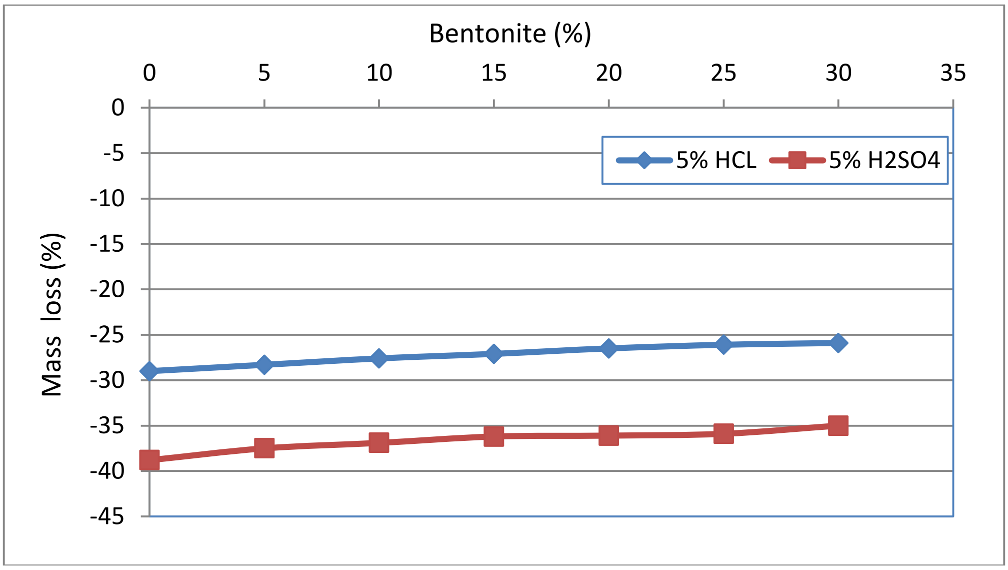

Figure 11. *Mass loss of mortar immersed in acid solution at 90 days*

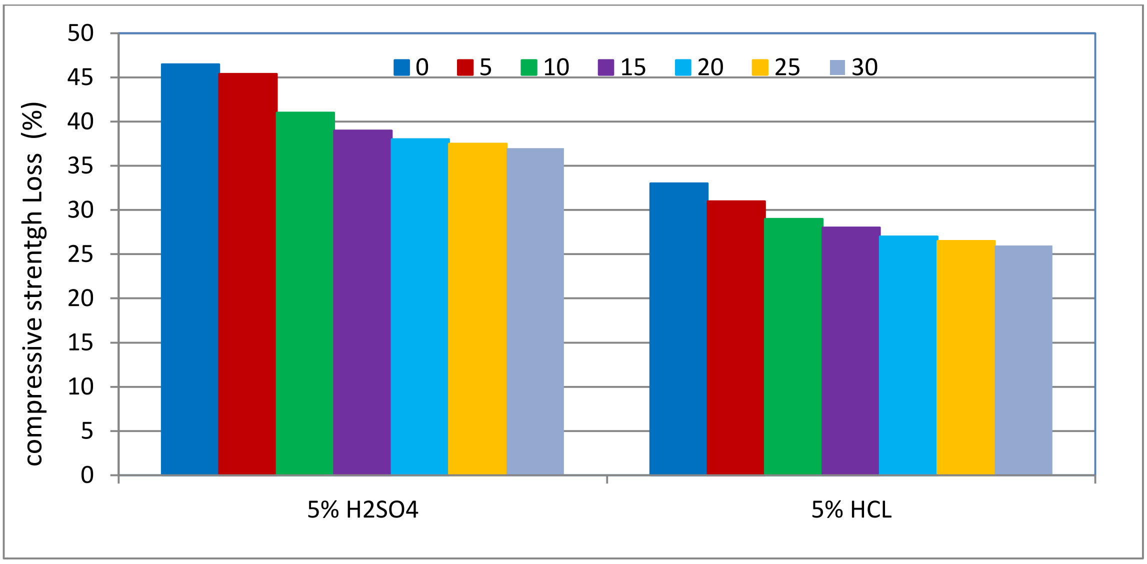

Figure 12.*Compressive strength loss of mortar immersed in acid solution at 90 days*

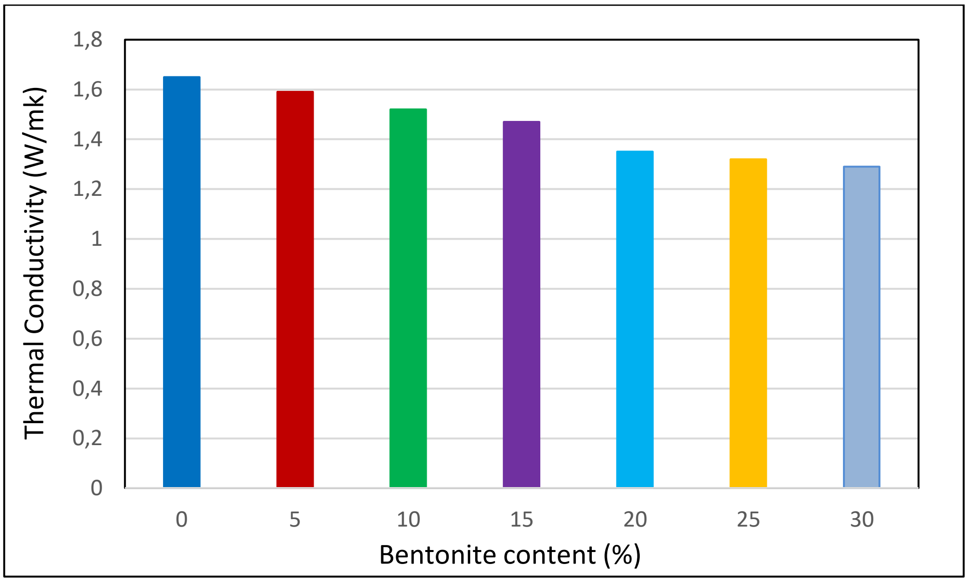

Figure 13. *Thermal conductivity evolution of bentonite mortar*

Figure 12 shows the compressive strength loss of mortar in HCL and H_2SO_4 solutions.It was found that mortars containing bentonite have a lower reduction in compressive strength loss than control mortar. Furthermore, the loss in compressive strength was more sensitive to H_2SO_4 solution than to the HCL solution. Also, the improvement in durabilityof mortar increased when the content of bentonite increased. This was due to the filler effect of bentonite because of its fine particle and to the low cement content means less lime is available to be attacked by the acid.

3.5 Effect of bentonite on thermal conductivity

Thermal conductivities of mortars with different amount of bentonite are presented in Figure 13. Results illustrated that the thermal conductivity decreased with increasing content of bentonite. Thermal conductivity of mortars without bentonite is 1.63 W/m.K, whereas mortars containing 5, 10, 15, 20, 25 and 40% diatomite, their thermal conductivity reach 1.59, 1.52, 1.47, 1.35, 1.32, and 1.29W/m.K, respectively. This can be relatedto the low conductivity of bentonite, estimated at 0.7 W/mk.

4. Conclusion

The present paper investigated the effect of partial replacement of cement with bentonite on the thermal conductivity, mechanical strengths, water absorption and the HCl andH_2SO_4acid resistance of mortars. The following conclusions can be drawn:

1. Increase bentonite as cement replacement exhibit high performance in comfort, since the thermal conductivity decreased.
2. Mortars containing 5%, 10%, and 15% bentonite as cement replacement exhibit a slightdrop in compressive and flexural strength. Beyond 20% of bentonite, a considerable decrease in themechanical strengths was observed.
3. Partial replacement of cement with bentonite decrease water absorption compared to the control mortar.

4- Durability under $H_2SO_4$and HCl acid solutions of mortarscontaining bentonite was better than the mortar without bentonite.

5- Mass and compressive strength losses decreased in H_2SO_4solution more than in the HCL solution.

From this research, cement can be partially replace with raw bentoniteuntil 20%. This will apply to mortars that will not be exposed to harmful environments. Also, replacing cement with bentonite enhance the insulation properties of mortars. Consequently, the findings of this study helpedto reduce the amount of cement in mortar manufacturing, thus they promoting eco-friendly construction practices and reducing the environmental impact of the building sector.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of 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
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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