Nigerian Journal of Technology (NIJOTECH)
Vol. 44, No. 2, June, 2025, pp.184 - 192
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v44i2.2

ECO-FRIENDLY CEMENT MORTARS USING WASTE CLAY BRICKS AND DRINKING WATER TREATMENT SLUDGE

AUTHORS:
S. Lagrani[1,*], A. Aziz[2], A. Bellil[3,*], K. Felaous[4], M. B. Ali[5], and M. Fekhaoui[6]

AFFILIATIONS:
[1,2,3,4,6]Geomaterials and Geo-Environment Team (GeoM&E), GEOBIO Laboratory, GEOPAC Center, Scientific Institute, Mohammed V University in Rabat, Morocco.
[5]Laboratory of Spectroscopy, Molecular Modeling, Materials, Nanomaterials, Water and Environment, Materials for Environment Team, ENSAM, Mohammed V University in Rabat, Morocco.

***CORRESPONDING AUTHORS:**
Email: bellil.abdelilah@gmail.com, slagrani@gmail.com

ARTICLE HISTORY:
Received: 13 February, 2025.
Revised: 13 May, 2025.
Accepted: 05 June, 2025.
Published: 07 July, 2025.

KEYWORDS:
Environmental Impact, Drinking water treatment sludge, Waste clay brick, Compressive strength.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract

The construction sector significantly contributes to environmental degradation, particularly due to the substantial CO_2 emissions associated with cement production. At the same time, large quantities of drinking water treatment sludge (DWTS) and waste clay bricks (WCB) are generated annually, leading to major environmental and logistical challenges due to their accumulation in landfills. In response to these issues, the development of low environmental impact materials incorporating industrial waste emerges as a necessary and sustainable alternative. In this context, the present study explores the potential of using these two types of waste, DWTS and WCB, to formulate a more environmentally friendly cement mortar. Two experimental series were conducted: (i) DWTS was used as a partial replacement for cement at substitution levels of 5%, 10%, 15%, and 20% after being calcined at *800 °C for one hour. (ii) In the second series, the DWTS replacement level was fixed at 10%, while WCB was used to replace sand in 25% increments, ranging from 0% to 100%. These mortar's performances were carefully assessed using several important criteria, including bulk density, water absorption, ultrasonic pulse velocity (UPV), compressive and flexural strength. The results show that 10% DWTS substitution led to a maximum compressive strength of 39.24 MPa and a flexural strength of 6.11 MPa at 28 days, compared to 36.34 MPa and 5.22 MPa for the control mix. However, WCB contents above 50% caused a clear decline in performance, with compressive and flexural strengths dropping to 22.87 MPa and 4.47 MPa, respectively, due to its porous and low-density nature. This dual strategy provides a sustainable answer for greener construction methods by drastically lowering CO_2 emissions, conserving natural resources, and reusing construction waste. These results show that using DWTS and WCB in cement mortar production is an excellent strategy for mitigating the negative impact of these wastes and protecting the environment.*

HOW TO CITE:
Lagrani, S., Aziz, A., Bellil, A., Felaous, K., Ali, M. B., and Fekhaoui, M. "Eco-Friendly Cement Mortars using Waste Clay Bricks and Drinking Water Treatment Sludge", *Nigerian Journal of Technology*, 2025; 44(2), pp. 184 – 192; https://doi.org/10.4314/njt.v44i2.2

1.0 INTRODUCTION

Significant environmental problems, like overuse of natural resources and greenhouse gas emissions, are brought on by the expansion of the building industry [1], [2]. Because of its heavy reliance on materials (such as cement, aggregates, and acer), this industry contributes to the depletion of natural resources and the damage of ecosystems [3], [4]. Due to the extensive extraction of its elements and the energy-intensive manufacture of cement, which accounts for 8% of worldwide anthropogenic CO_2 emissions, concrete, a crucial component of this industry, stands out for having a high environmental impact [5], [6].

In the context of sustainable construction and the urgent need to reduce environmental impacts, finding sustainable alternatives to conventional building materials has become a top priority. The integration of industrial wastes such as DWTS and WCB is emerging as a promising alternative [7], [8], [9], [10], [11]. These materials offer the possibility of partially substituting cement and natural aggregates, thereby reducing CO_2 emissions while minimizing production costs.

As an additional cementitious material, calcined drinking water treatment sludge (DWTS) has been the subject of numerous recent investigations. The high concentration of silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3) in these sludges throughout the calcination process indicates considerable potential. The transformation of silica and alumina, initially present in inert crystalline form, into a reactive amorphous phase at temperatures between 600 and 800°C, enhances the material's properties [10], [12], [13]. Research has shown that the incorporation of calcined sludge, up to 15 % of cement replacement, results in composites with mechanical strength and porosity characteristics comparable to those of traditional cement [10].

Research into the substitution of fine aggregates for waste materials in concrete and mortar manufacture has attracted growing interest, with the aim of preserving non-renewable resources. Clay brick waste is one of the materials used to replace aggregates in these mixes [14], [15]. The results revealed that the mechanical properties are influenced by the grain size and the degree of WCB replacement by aggregates in the concrete [16], [17], [18]. Debieb and Kenai [19] used both fine and coarse crushed brick aggregates in mortar mixes. They observed that percentages of 50% for fine aggregates and 25% for coarse aggregates were the most appropriate, highlighting the effectiveness of these recycled materials. Corinaldesi [20] observed that the use of finely crushed red brick in mortar production led to a decrease in both mechanical properties while improving mortar adhesion. Ge et al. [21] examined the effect of substituting river sand with recycled fine clay brick aggregate (RFCBA) at replacement levels of 30%, 60%, and 100% on the properties of both fresh and hardened mortar. They showed that at a replacement rate of 30%, the strength of the mortar did not decrease significantly. Furthermore, when 100% RFCBA was used, the reduction in strength did not exceed 20%.

Waste clay bricks was used to replace sand in this study at volumes of 25%, 50%, 75%, and 100%, while DWTS calcined at 800°C was used to replace cement in proportions of 5%, 10%, 15%, and 20%. The mechanical characteristics, bulk density, water absorption, and ultrasonic pulse velocity (UPV) of the synthesized mortars were assessed. By combining sewage sludge and recycled clay bricks, this research seeks to promote the creation of environmentally friendly building materials by the principles of the circular economy, all the while guaranteeing the structural performance of the newly created materials.

2.0 MATERIALS AND METHODS

2.1 Raw materials

The materials used in this study include Portland cement, drinking water treatment sludge, and fine aggregates (river sand and crushed waste clay brick) (Figure 1).

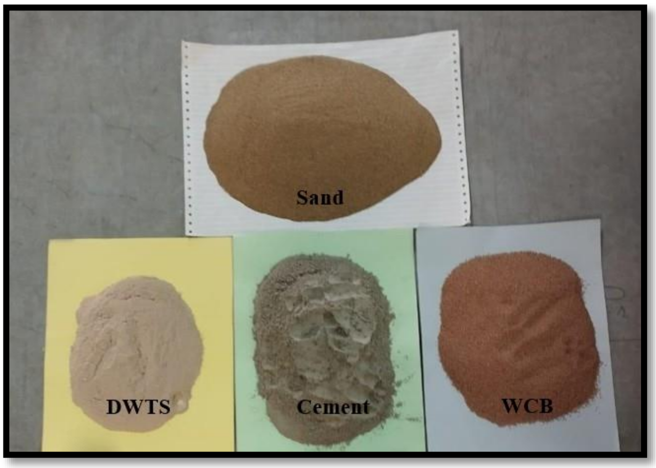

Figure 1: The materials used in this study

2.1.1 Portland cement

The ordinary Portland cement used is CEM II (CPJ 45), manufactured by Holcim-Lafarge in Morocco, and complies with the specifications of Moroccan standard NM 10.01.004 [22]. After 28 days of curing, it reached an average compressive strength of 40 MPa and has a specific gravity of 3.15 g/cm^3. The chemical composition of Portland cement is detailed in Table 1.

2.1.2 Drinking water treatment sludge (DWTS)

The sludge used in this investigation came from the conventional raw water treatment plant at Oum Azza, Morocco, about 17 kilometers from Rabat. The following procedure was used to treat the raw sludge to prepare it as an additional cementitious material: First, it was sun-dried for 72 hours to get rid of any remaining moisture. It was subsequently processed in a ball mill, and a sieve was used to remove particles smaller than 63 µm from the resultant powder; The sludge was then calcined in an

https://doi.org/10.4314/njt.v44i2.2

electric furnace that could be programmed to heat it at a regulated pace of 10°C per minute. The material was left to naturally drop to room temperature after the 800 °C goal temperature was reached and maintained for an hour. The chemical analysis of the drinking water treatment sludge after calcination (Table 1) reveals a highly aluminous composition, characterized by a high Al_2O_3 content reaching 68.67%. The sludge also exhibits a moderate silica content, while the combined amount of iron and calcium oxides remains relatively low, with Fe_2O_3 and CaO together accounting for no more than 4.02%.

Table 1: Chemical composition (%, by mass) of the cement and DWTS used in this work

Oxides	SiO_2	Al_2O_3	CaO	K_2O	Fe_2O_3	SO_3	MgO	P_2O_5	TiO_2	MnO	Na_2O	L.O.I*
Cement	16.40	4.24	68.30	0.23	3.00	2.27	2.39	0.22	0.27	0.07	0.02	2.59
Calcined DWTS	18.57	68.67	2.00	0.75	2.02	1.17	0.85	0.4	0.12	2.21	0.45	2.82

* Loss on Ignition

2.1.3 Sand and waste clay bricks (WCB)

Sand employed in this study is river sand from Kenitra, Morocco, which has a 65% carbonate shell fragment rate and fine, spherical grains that are mostly made of quartz. The sand was cleaned carefully before use, dried for 24 hours at 105 °C, and sieved to keep granules no larger than 2 millimeters.

Table 2: The physical properties of the sand and WCB aggregates

Proprieties	Sand	WCB	Relevant standard
Density g/cm^3	2.62	2.08	NM 10.1.149 [23]
Water absorption %	1	10.4	NM 10.1.149 [23]
Friability coefficient %	--	26	NM 10.1.150 [24]

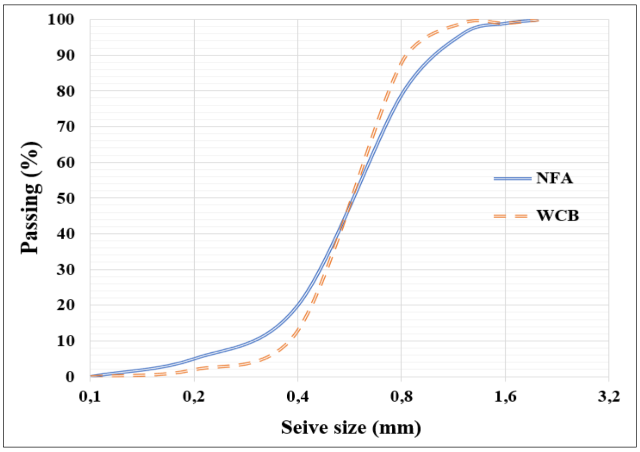

Figure 2: Particle size distribution curves of fine aggregates

The waste clay bricks (WCB) used In this study were derived from the production process of clay bricks, in the form of crushed fragments. These wastes were carefully sorted to remove fine particles and then crushed to attain an appropriate particle size distribution, comparable to that of river sand (ranging between 0.1 and 2 mm). Before use, the WCB aggregates were sieved and treated by soaking in water for 24 hours to remove debris and impurities. These particles were characterized by a textured surface, irregular edges, and sharp corners. The physical properties of the sand and WCB aggregates are detailed in Table 2. The particle size distribution of the natural and recycled fine aggregates is illustrated in Figure 2.

2.1.4 Mixing water and superplasticizer

The mixing water used in this research was sourced from the municipal drinking water system of Rabat, Morocco. For all mixtures, the water-to-binder ratio was maintained at 0.5. Additionally, a superplasticizer supplied by Sika Maroc was incorporated into the mixing water at a dosage of 1% of the total binder weight (cement + calcined sludge) to enhance the workability of the mortar mixtures.

2.2 Synthesis Method

In this study, nine mortar mix samples were prepared. The first sample served as a control, with no substitution of either cement or sand. Four additional mixtures were developed by substituting cement with calcined sludge at rates of 5%, 10%, 15%, and 20% by mass. Furthermore, four more mixtures were developed with a constant 10% substitution of cement by calcined sludge while progressively replacing sand with red brick waste aggregates by volume. The specific details of the prepared mixtures are provided in Table 3.

In this Table 3, the nomenclature M(x; y) is used, where x represents the percentage of cement replacement with DWTS, and y indicates the percentage of sand replacement with WCB aggregates. The samples were demolded 24 hours after casting and immersed in a water container to continue the curing process. They were maintained at an average ambient temperature of 22 ± 2 °C.

Table 3: Composition of all mortar mix designs (kg/m^3).

Mix reference	Bander		Fin aggregates	
	Cement	DWTS	Sand	WCB
M(0 ; 0)	568	–	1412	–
M(5 ; 0)	539.6	28.4	1412	–
M(10 ; 0)	511.2	56.8	1412	–
M(15 ; 0)	482.8	85.2	1412	–
M(20 ; 0)	454.4	113.6	1412	–
M(10 ; 25)	511.2	56.8	1059	353
M(10 ; 50)	511.2	56.8	706	706
M(10 ; 75)	511.2	56.8	353	1059
M(10 ; 100)	511.2	56.8	–	1412

2.3 Characterization Methods

Various tests were conducted to investigate the influence of the materials on the properties of the prepared mortars (Figure 3).

Bulk density: After 28 days of curing, the samples' bulk density was determined. This was accomplished by weighing each sample and measuring its dimensions with a digital caliper to establish its volume. The bulk density (ρ) was then determined using the equation below 1 :

$$\rho = \frac{m}{V} \qquad (1)$$

Where, ρ: density (kg/m^3); *m*: mass of the sample (kg); *V*: volume of the sample (m^3).

Water Absorption: The procedure outlined in the ASTM C642 [25] was adhered to conduct the water absorption test. All specimens were first dried in an oven at 105 ± 2°C after a 28-day curing period. Weighing was done every 24 hours until a consistent mass was achieved. After cooling, the samples were submerged in water and weighed every day for a full day. The water absorption of the prepared mortar was determined using Equation 2:

$$\boldsymbol{w} = \left(\frac{W_w - W_d}{W_d}\right) \times 100 \qquad (2)$$

Where, W: water absorption (%); W_w: weight of the wet specimens (g); W_d: weight of the oven-dried specimens (g).

***Mechanical Properties*:** In accordance with ASTM C109 [26] guidelines, the hydraulic press (Controlab, 250 kN capacity) was used to measure the synthesized materials' compressive and flexural strengths at a loading rate of 0.5 MPa/s. Cubic specimens with a side length of 50 millimeters were used to evaluate compressive strength at 7 and 28 days. Additionally, 40×40×160 mm prisms were used for flexural strength testing, which was performed using the three-point bending method. Each test was performed on three specimens per mix, with the reported results representing the average of the three measurements.

***P-Wave Velocity*:** The measurement of the P-wave velocity of the mortar samples was carried out using NFP 94-411 type TICO equipment. For each mix, three measurements were conducted, and the reported values correspond to the average of these three readings.

Figure 3: Testing procedures for mortar samples: (a) hydraulic press, (b) compression test, (c) flexural test, (d) ultrasonic pulse velocity measurement, and (e) sample weight measurement

3.0 RESULTS AND DISCUSSION

3.1 Bulk Density and Water Absorption Results

The bulk density and water absorption results of the mortars are illustrated in Figure 4. The bulk density measurements indicate that most mixes have densities ranging from 2098 kg/m^3 to 1910 kg/m^3. The M(5; 0) sample exhibits a density similar to that of the reference, while the M(10-0) sample shows a slight increase of 0.24% compared to M(0; 0). Conversely, the M(15; 0) and M(20; 0) samples present density reductions of 2.2% and 3.7%, respectively, suggesting that the gradual replacement of cement with mud negatively affects density, albeit to a limited extent. Additionally, mortars incorporating 25% WCB experience a slight density reduction of 1.39%, while higher substitution rates lead to significant density decreases, reaching up to 8.74%. This is attributed to the lower density of WCB relative to natural fine aggregates and the presence of a porous structure and microcracks formed during secondary mechanical grinding [27].

Regarding water absorption, the results show that the incorporation of 5% and 10% calcined DWTS reduces water absorption by 2.20% and 4.51%, respectively. This reduction is attributed to the pozzolanic effect of calcined DWTS, which is rich in alumina and amorphous silica (Table 1). These chemical components contribute to the formation of C-S-H and C-A-S-H gels, which fill the pores and enhance the structural integrity of the material, thereby reducing water absorption. However, at a 15% substitution rate, water absorption is almost the same as in the control mix, increasing by 5.43% in the M(20; 0) mix. This is probably because the cement's reactive capacity is saturated, leaving behind unreacted DWTS particles that weaken the microstructure by acting as inert fillers. These unreacted particles can weaken the microstructure and create residual pores, increasing the porosity of the mortars [28]. Furthermore, replacing natural sand with WCB results in higher water absorption rates than the reference, with values of 11.18%, 12.15%, 13.44%, and 15.03% for the M(10; 25), M(10; 50), M(10; 75), and M(10; 100) mixes, respectively, compared to 10.41% for the control mix. This increase is attributed to WCB's porous structure and lower density relative to sand, consistent with findings from previous studies [19], [29].

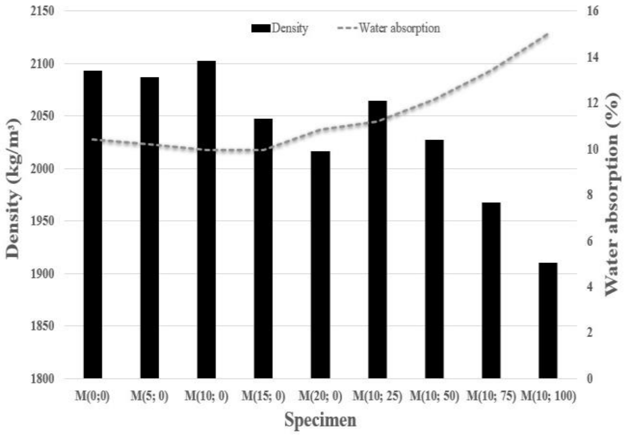

Figure 4: Density and water absorption results for mortar mixes after 28 days of curing

3.2 Compressive Strength

Figure 5 illustrates the variation in compressive strength of mortar specimens. At 7 days, the compressive strength is lower than that of the control mix, likely due to the pozzolanic reaction of calcined DWTS, which is not the primary factor at an early age [30], [31]. At 28 days, an increase in compressive strength was recorded compared to the control mortar when 10% of the cement was replaced with calcined DWTS. This increase is approximately 3% and 8% for the M(5; 0) and M(10; 0) mixes, respectively. Conversely, the mortar with 15% substitution exhibits a slight reduction compared to the M(0; 0) mix. The decrease in compressive strength became more pronounced at a substitution rate of 20% at 28 days. Comparable results were found by Duan et al. [8] who noted that the compressive strength of mortars improved when the cement substitution rate with calcined DWTS did not exceed 10%. The improvement in compressive strength can be ascribed to the pozzolanic reaction of the calcined DWTS powder.

The amorphous phase present in DWTS (primarily composed of silica and alumina) reacts with the calcium hydroxide (CH) released during cement hydration, producing additional calcium silicate hydrate (C-S-H) and calcium alumino-silicate hydrate (C-A-S-H), which strengthens the mortar matrix and enhances its mechanical performance. However, beyond a 10% substitution rate, the reduction in cement content limits CH production, thereby slowing the formation of C-S-H through pozzolanic reactions. This weakens the matrix cohesion and reduces compressive strength.

The compressive strength results for mortars prepared with WCB incorporation at different curing ages (7 and 28 days) are illustrated in Figure 5. At 7 days, all mixes exhibited compressive strength lower than that of the control mix. At 28 days, the compressive strength of the M(10, 25) mix remains nearly identical to that of the control. This may be ascribed to the pozzolanic reaction. The pozzolanic reaction of DWTS, which mitigates the trend of strength reduction with the substitution of sand by WCB. Mixes with substitution rates of 50%, 75%, and 100% exhibit a reduction of approximately 12%, 29%, and 37% in compressive strength, respectively, compared to the M(0, 0) mix. This decrease can be ascribed to the porous structure and microcracks in the WCB after secondary mechanical grinding, as well as its lower density compared to natural sand.

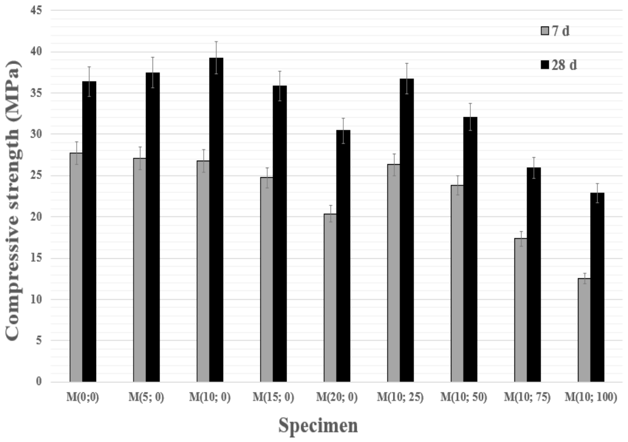

Figure 5: Results of compressive strength for the mortar mixtures

3.3 Flexural Strength

The variations in the flexural strength of mortars as a function of cement replacement by calcined DWTS and sand replacement by WCB aggregates are shown in Figure 6. At 7 days of curing, the flexural strength of all mixes is lower than that of the control mix. However, At 28 days, the control mix M(0,0) exhibited a flexural strength of 5.22 MPa. Progressively increasing the cement replacement rate with DWTS improved the flexural strength, peaking at a 10% substitution rate. For instance, the M(5; 0) mix exhibits a strength of 5.65 MPa, an approximately 8% increase compared to the control, while the M(10; 0) mix reaches 6.11 MPa, representing a 17% improvement. As explained for compressive strength, these results suggest that incorporating up to 10% calcined DWTS promotes the formation of additional C-S-H and C-A-S-H, contributing to the consolidation of the mortar matrix. At a substitution rate of 15%, the flexural strength of the prepared mortar is 5.24 MPa, comparable to that of the control. However, at a 20% substitution rate, a more noticeable decrease was observed, with a strength of 5.03 MPa, indicating that higher DWTS substitution begins to negatively affect matrix cohesion.

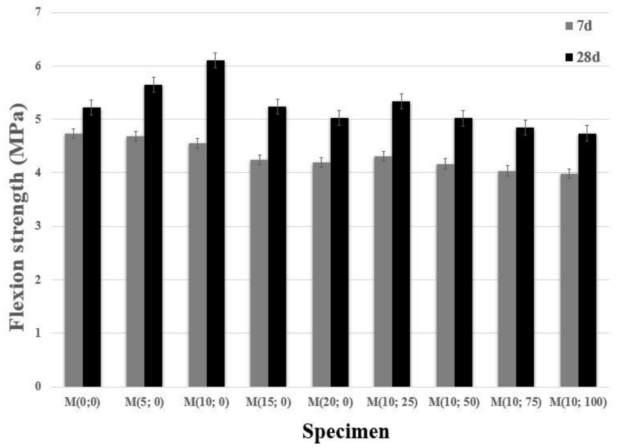

Figure 6: Results of flexural strength for the mortar mixtures

The results for sand replacement by WCB aggregates in the mix show a general trend of decreasing flexural strength with increasing WCB content. The M(10; 25) mix exhibits a strength of 5.34 MPa, slightly higher than the control. Despite the 25% sand replacement by WCB aggregates, this mix maintains superior flexural strength, likely due to the presence of 10% calcined DWTS. This proportion of DWTS facilitates the formation C-S-H, contributing to the improvement in flexural strength. However, the M(10; 50), M(10; 75), and M(10; 100) mixes exhibit progressive strength reductions, with values of 5.02 MPa, 4.85 MPa, and 4.74 MPa, respectively. This decline may be due to the porous nature and microcracks within the WCB aggregates, along with their lower density compared to the natural aggregate, which weakens the mortar structure.

3.4 Ultrasonic Pulse Velocity (UPV) Results

Figure 7 shows UPV results for various mixes after 28 days of curing. The UPV test is a non-destructive method commonly employed to assess concrete quality and detect voids. It is also used to examine various properties of concrete, including its durability [32].

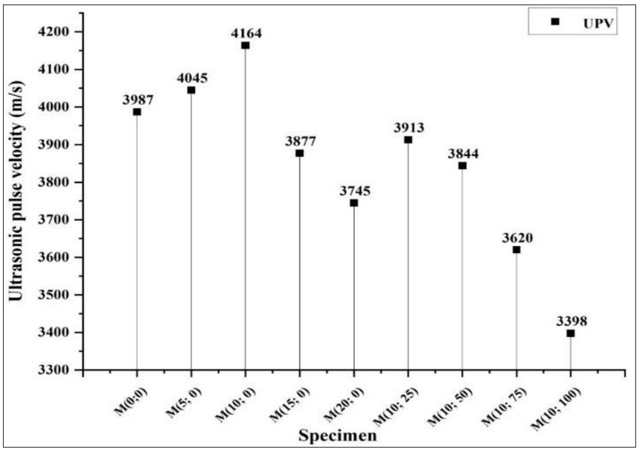

Figure 7: UPV measurements of mortar mixtures after 28 days

The UPV values measured for all mixtures range from 3398 m/s for M(10; 100) to 4164 m/s for M(10; 0). This indicates that most mixes can be classified as "good" according to the concrete quality criteria by Shafigh et al. [33], except for M(10; 100), which may be categorized as "doubtful" due to its low UPV value. Mixes with partial cement replacement by DWTS show a notable increase in UPV up to a substitution rate of 10%. For replacement levels of 5% and 10%, the increases are approximately 1.5% and 4.4%, respectively, compared to the control mix M(0; 0), which has a UPV value of 3987 m/s. This suggests that at these substitution levels, DWTS enhances compactness by filling voids in the mix, thereby improving its mechanical properties. These results align with those observed in the compressive strength section. However, beyond a 10% replacement of cement with DWTS, UPV values decrease, potentially indicating a progressive degradation in material quality. For the mixtures containing WCB as a partial replacement for sand, it can be observed that as the level of sand replacement with WCB increases, the UPV values of the mortars progressively decrease. This result can be attributed to the higher porosity of WCB compared to sand.

Figure 8 illustrates the regression between ultrasonic pulse velocity (UPV) and compressive strength after 28 days. The linear regression equation represents the relationship between compressive strength (y) and UPV (x). The slope of the equation indicates the rate of change in compressive strength with respect to UPV, showing that for every 1 m/s increase in ultrasonic pulse velocity, the compressive strength increases by 0.0235 MPa. This highlights a positive correlation, meaning higher P-wave velocities are generally associated with higher compressive strengths. This positive relationship suggests that higher UPV values, typically indicative of improved material density and a reduction in internal defects, contribute to enhanced compressive strength. Meanwhile, the intercept (−57.5) represents the predicted compressive strength when UPV is zero. Although this value may not have a physical meaning (since UPV cannot realistically be zero), it serves to position the regression line within the data context.

$$y = 0.0235\,x - 57.5 \qquad (3)$$

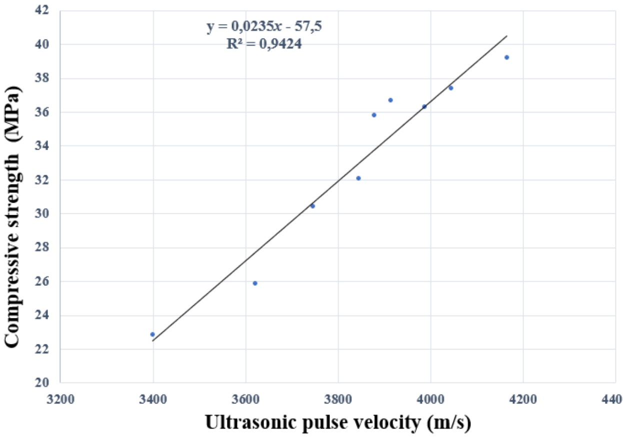

Figure 8: Linear regression between UPV and compressive strength

The high R^2 (coefficient of determination) value confirms that the ultrasonic pulse velocity is a reliable predictor of compressive strength in the dataset, which confirms that the changes in UPV can explain 94.24% of the variability in compressive strength. And the non-explained variability in compressive strength is due to factors not included in the model or random noise. This result is consistent with previous studies in the literature. Saha et al. [34] revealed that UPV can accurately predict the compressive strength data of concrete made with lightweight recycled aggregates and nickel slag. Similarly, Del Rio et al. [35] reported an exponential relationship between concrete compressive strength and UPV, with an R^2 of 0.92, demonstrating a strong predictive capability. Additionally, Omer et al. [36] highlighted the use of UPV to predict the compressive strength of geopolymer mortars, further supporting the idea of a robust predictive relationship.

The residual analysis and the statistical significance of the slope further validate the model, confirming that UPV is an effective and reliable technique for assessing material performance in practical construction and engineering applications. The strong fit of the regression model to the data indicates that the linear equation provides accurate estimates of compressive strength across the observed range of P-wave velocities.

4.0 CONCLUSION

Based on the results of this research, the following can be deduced:

i. Replacing cement with up to 10% DWTS increases the mechanical strength of cement mortar by 8% compared with the reference sample. However, when natural sand is substituted with clay brick waste as aggregate, the mechanical properties of the mortar decrease, particularly for mortars with high substitution levels (≥ 50%). This decrease in strength can be attributed to the low density and porous structure of the WCB.
ii. Replacing natural sand with clay brick waste leads to a decrease in ultrasonic pulse velocity values. This decrease intensifies as the substitution rate increases.
iii. The water absorption of WCB replacement mixes increases progressively as the sand substitution rate by WCB increases. At the same time, the density of these mixes decreases as substitution progresses.

This study shows that using wastes, such as DWTS and WCB, in cement mortar production is an excellent strategy for mitigating the negative impact of these wastes and protecting the environment. It provides a promising approach to sustainable construction by reducing CO_2 emissions and preserving natural resources through reduced cement and sand consumption.

REFERENCES

[1] Aziz, A., Driouich, A., Felaous, K., and Bellil, A. "Box-Behnken design based optimization and characterization of new eco-friendly building materials based on slag activated by diatomaceous earth", *Construction and Building Materials*, vol. 375, p. 131027, avr. 2023, doi: 10.1016/j.conbuildmat.2023.131027.

[2] Felaous, K., Aziz, A., Achab, M., Fernández-Raga, M., and Benzaouak, A. "Optimizing

Alkaline Activation of Natural Volcanic Pozzolan for Eco-Friendly Materials Production: An Investigation of NaOH Molarity and Na2SiO3-to-NaOH Ratio", *Sustainability*, vol. 15, nº 5, p. 4453, mars 2023, doi: 10.3390/su15054453.

[3] Gregg, J. S., Andres, R. J., and Marland, G. "China: Emissions pattern of the world leader in CO_2 emissions from fossil fuel consumption and cement production", *Geophysical Research Letters*, vol. 35, nº 8, p. 2007GL032887, avr. 2008, doi: 10.1029/2007GL032887.

[4] Habert, G. "Environmental impact of Portland cement production", in *Eco-Efficient Concrete*, Elsevier, 2013, p. 3-25. doi: 10.1533/9780857098993.1.3.

[5] Aziz, A., Felaous, K., Alomayri, T., and Jindal, B. B. "A state-of-the-art review of the structure and properties of laterite-based sustainable geopolymer cement", *Environmental Science and Pollution Research*, vol. 30, nº 19, p. 54333-54350, mars 2023, doi: 10.1007/s11356-023-26495-3.

[6] Huseien, G. F., and Shah, K. W. " Durability and life cycle evaluation of self-compacting concrete containing fly ash as GBFS replacement with alkali activation", *Construction and Building Materials*, vol. 235, p. 117458, févr. 2020, doi: 10.1016/j.conbuildmat.2019.117458.

[7] Abdellatief, M., Elemam, W. E., Alanazi, H., and Tahwia, A. M. "Production and optimization of sustainable cement brick incorporating clay brick wastes using response surface method", *Ceramics International*, vol. 49, nº 6, p. 9395-9411, mars 2023, doi: 10.1016/j.ceramint.2022.11.144.

[8] Duan, W., Zhuge, Y., Pham, P. N., Chow, C. W. K., Keegan, A., and Liu, Y. "Utilization of Drinking Water Treatment Sludge as Cement Replacement to Mitigate Alkali–Silica Reaction in Cement Composites", *Journal of Composites Science*, vol. 4, nº 4, p. 171, nov. 2020, doi: 10.3390/jcs404 0171.

[9] Lagrani, S., Aziz, A., Bellil, A., Felaous, K., Mohammed, A., and Fekhaoui, M. "Synthesis and Characterization of Slag-Sludge-Based Eco-Friendly Materials – Industrial Implications", *Journal of Ecological Engineering*, vol. 24, nº 1, p. 227-238, janv. 2023, doi: 10.12911/22998993/156078.

[10] Owaid, H. M., Hamid, R., and Taha, M. R. "Influence of thermally activated alum sludge ash on the engineering properties of multiple-blended binders concretes", *Construction and Building Materials*, vol. 61, p. 216-229, juin 2014, doi: 10.1016/j.conbuildmat.2014.03.014.

[11] Ukwizagira, G., Nezerwa, B., and Bush, H. U. G. "Effect of Crushed Clay Brick as Partial Replacement of Fine Aggregate in Concrete", *Mediterranean Journal of Basic and Applied Sciences*, vol. 07, nº 01, p. 90-99, 2023, doi: 10.46382/MJBAS.2023.7108.

[12] Bohórquez González, K., Pacheco, E., Guzmán, A., Avila Pereira, Y., Cano Cuadro, H., and Valencia, J. A. F. "Use of sludge ash from drinking water treatment plant in hydraulic mortars", *Materials Today Communications*, vol. 23, p. 100930, juin 2020, doi: 10.1016/j.mtcomm.2020.100930.

[13] Owaid, H. M., Hamid, R., and Taha, M. R. "Durability properties of multiple-blended binder concretes incorporating thermally activated alum sludge ash", *Construction and Building Materials*, vol. 200, p. 591-603, mars 2019, doi: 10.1016/j.conbuildmat.2018.12.149.

[14] Klak, F. S., Saleh, H., and Tais, A. S. "Recycling of crushed clay bricks as fine aggregate in concrete and cement mortar", *Australian Journal of Structural Engineering*, vol. 24, nº 1, p. 67-76, janv. 2023, doi: 10.1080/13287982.2022.2098600.

[15] Huang, Q., Zhu, X., Xiong, G., Wang, C., Liu, D., and Zhao, L. "Recycling of crushed waste clay brick as aggregates in cement mortars: An approach from macro- and micro-scale investigation", *Construction and Building Materials*, vol. 274, p. 122068, mars 2021, doi: 10.1016/j.conbuildmat.2020.122068.

[16] Yang, J., Du, Q., and Bao, Y. "Concrete with recycled concrete aggregate and crushed clay bricks", *Construction and Building Materials*, vol. 25, nº 4, p. 1935-1945, avr. 2011, doi: 10.1016/j.conbuildmat.2010.11.063.

[17] Cachim, P. B. "Mechanical properties of brick aggregate concrete", *Construction and Building Materials*, vol. 23, nº 3, p. 1292-1297, mars 2009, doi: 10.1016/j.conbuildmat.2008.07.023.

[18] Adamson, M., Razmjoo, A., and Poursaee, A. "Durability of concrete incorporating crushed brick as coarse aggregate", *Construction and Building Materials*, vol. 94, p. 426-432, sept. 2015, doi: 10.1016/j.conbuildmat.2015.07.056.

[19] Debieb, F., and Kenai, S. "The use of coarse and fine crushed bricks as aggregate in concrete", *Construction and Building Materials*, vol. 22, nº 5, p. 886-893, mai 2008, doi: 10.1016/j.conbuildmat.2006.12.013.

[20] Corinaldesi, V. "Environmentally-friendly bedding mortars for repair of historical

buildings", *Construction and Building Materials*, vol. 35, p. 778-784, oct. 2012, doi: 10.1016/j.conbuildmat.2012.04.131.

[21] Ge, Z., Feng, Y., Zhang, H., Xiao, J., Sun, R., and Liu, X. "Use of recycled fine clay brick aggregate as internal curing agent for low water to cement ratio mortar", *Construction and Building Materials*, vol. 264, p. 120280, déc. 2020, doi: 10.1016/j.conbuildmat.2020.120280.

[22] Moroccan Standard NM 10.1.004, "Liants hydrauliques, Ciments et les constituants des ciments", 2018.

[23] Moroccan Standard NM 10.1.149, "Mesures des masses spécifiques, Coefficient d'absorption et Teneur en eau des sables", 1995.

[24] Moroccan Standard NM 10.1.150, "Mesure du coefficient de friabilité des sables", 1995.

[25] ASTM C642, "Standard test method for density, absorption, and voids in hardened concrete", *ASTM, ASTM International*, 2013.

[26] ASTM C109, "Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube specimens)", 2002.

[27] Dang, J., Zhao, J., Hu, W., Du, Z., and Gao, D. "Properties of mortar with waste clay bricks as fine aggregate", *Construction and Building Materials*, vol. 166, p. 898-907, mars 2018, doi: 10.1016/j.conbuildmat.2018.01.109.

[28] Nasr, M. S., Shubbar, A. A., Abed, Z. A.-A. R., and Ibrahim, M. S. "Properties of eco-friendly cement mortar contained recycled materials from different sources", *Journal of Building Engineering*, vol. 31, p. 101444, sept. 2020, doi: 10.1016/j.jobe.2020.101444.

[29] Wu, H., Xiao, J., Liang, C., and Ma, Z. "Properties of Cementitious Materials with Recycled Aggregate and Powder Both from Clay Brick Waste", *Buildings*, vol. 11, nº 3, p. 119, mars 2021, doi: 10.3390/buildings11030119.

[30] Bellil, A., Aziz, A., El Amrani El Hassani, I.-I., Achab, M., El Haddar, A., and Benzaouak, A. "Producing of Lightweight Concrete from Two Varieties of Natural Pozzolan from the Middle Atlas (Morocco): Economic, Ecological, and Social Implications", *Silicon*, vol. 14, nº 8, p. 4237-4248, juin 2022, doi: 10.1007/s12633-021-01155-8.

[31] Liu, Y., Zhuge, Y., Chow, C. W., Keegan, A., Pham, P. N., Li, D., Oh, J., Siddique, R. "The potential use of drinking water sludge ash as supplementary cementitious material in the manufacture of concrete blocks", *Resources, Conservation and Recycling*, vol. 168, p. 105291, mai 2021, doi: 10.1016/j.resconrec.2020.105291.

[32] Lafhaj, Z., Goueygou, M., Djerbi, A., and Kaczmarek, M. "Correlation between porosity, permeability and ultrasonic parameters of mortar with variable water / cement ratio and water content", *Cement and Concrete Research*, vol. 36, nº 4, p. 625-633, avr. 2006, doi: 10.1016/j.cemconres.2005.11.009.

[33] Shafigh, P., Nomeli, M. A., Alengaram, U. J., Mahmud, H. B., and Jumaat, M. Z. "Engineering properties of lightweight aggregate concrete containing limestone powder and high volume fly ash", *Journal of Cleaner Production*, vol. 135, p. 148-157, nov. 2016, doi: 10.1016/j.jclepro.2016.06.082.

[34] Saha, A. K., Majhi, S., Sarker, P. K., Mukherjee, A., Siddika, A., Aslani, F., & Zhuge, Y. "Non-destructive prediction of strength of concrete made by lightweight recycled aggregates and nickel slag", *Journal of Building Engineering*, vol. 33, p. 101614, janv. 2021, doi: 10.1016/j.jobe.2020.101614.

[35] Del Río, L. M., Jiménez, A., López, F., Rosa, F. J., Rufo, M. M., and Paniagua, J. M. "Characterization and hardening of concrete with ultrasonic testing", *Ultrasonics*, vol. 42, nº 1-9, p. 527-530, avr. 2004, doi: 10.1016/j.ultras.2004.01.053.

[36] Omer, S. A., Demirboga, R., and Khushefati, W. H. "Relationship between compressive strength and UPV of GGBFS based geopolymer mortars exposed to elevated temperatures", *Construction and Building Materials*, vol. 94, p. 189-195, sept. 2015, doi: 10.1016/j.conbuildmat.2015.07.006.