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Influence of Date Palm Waste Aggregates on the Mechanical Strengths and Hygroscopicity Behavior of Earth-Based Composites

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ABSTRACT

The underutilization of natural waste from date palm plantation maintenance presents an opportunity for the production of sustainable building materials. This study investigates the mechanical properties and environmental sustainability of adobe bricks reinforced with date palm waste (DPW) and a small percentage of cement. Adobe bricks were stabilized using 7% cement by weight and varying proportions of DPW (0%, 0.5%, 1%, and 1.5% by weight), followed by curing under two distinct conditions: moist storage (MS) and open-air (AF). It was observed that bricks cured under MS conditions significantly outperformed those cured in AF, evidenced by a 47.05% reduction in capillary absorption coefficient compared to the reference brick. Despite a decrease in compressive strength due to DPW incorporation, the bricks exhibited increases in capillary and total absorption while still satisfying earth construction standards. Notably, flexural strength improved by 41.66% under MS curing. Enhanced erosion and abrasion resistance, as well as improved performance throughout wetting/drying cycles, were also recorded. These enhancements underscore the potential of DPW as a renewable additive in the formulation of adobe bricks for ecological and durable housing. The study not only proposes a novel use for date palm byproducts but also contributes to the advancement of environmentally-friendly construction methodologies.

1. INTRODUCTION

The construction industry, a significant contributor to global CO_2 emissions, with estimates attributing 5 to 8% of total emissions to cement production [1], is undergoing a transformative shift towards sustainability. Raw earth construction techniques, boasting millennia of historical use across diverse regions, emerge as a cornerstone of this transition, with adobe as a prime example due to its simplicity and minimal equipment requirements. Traditional adobe practices, which involve the use of plastic state earth and straw fibers to curb shrinkage and cracking during the natural drying process, are rooted in empirical knowledge rather than scientific validation [2].

In response to the mechanical limitations of adobe, evidenced by compressive strengths ranging from 0.6 to 7 MPa and notably low tensile strengths—approximately 10% of compressive values [3]—contemporary research advocates for the incorporation of chemical binders and reinforcing fibers. This aligns adobe with current construction standards through a scientific lens. The vulnerability of adobe to water remains a critical challenge, addressed historically through various physical and chemical stabilization methods, prominently featuring cement and lime [4-8]. Notably, the application of Ordinary Portland Cement (OPC) has been prevalent for nearly a century [9, 10], with its efficacy on soils with moderate to low plasticity and a Plasticity Index (PI) below 20% being well-documented [11, 12]. An increase in clay content necessitates a proportional rise in cement to stabilize expansive soils [13, 14].

The pursuit of ecological stabilization has led researchers to explore natural waste, such as straw [15-17], kenaf [18, 19], jute [20], banana [21], and wood fibers [22], as potential additives. Date palm waste (DPW) has recently garnered attention, with studies indicating promising enhancements in the mechanical and thermal performance of earth constructions incorporating DPW [23-28]. Khoudja et al. [29] noted that a 10% DPW inclusion compromised mechanical properties but augmented thermal insulation. In contrast, Niyomukiza et al. [30] reported an increase in compressive strength with the addition of 20% palm leaves and a 25% combination of palm leaves and pits.

Despite these advances, research on DPW's impact on adobe sustainability is scarce. Zaidi et al. [31] observed that DPW integration bolstered tensile strength by 67% while also improving resistance to erosion, abrasion, and sulfate attack during durability tests, although some drawbacks in compressive strength and water absorption were noted.

The current investigation seeks to address the limited knowledge on the utilization of DPW, particularly as a cement aggregate in adobe brick stabilization, by examining the mechanical, thermal, and durability properties in the context of Algerian Saharan housing. With Algeria's over 20 million date palm trees yielding vast quantities of renewable waste [32], the potential for DPW in construction materials is significant, yet its application remains underexplored as the waste is often burned or underutilized [33].

This study's objective is to evaluate the incorporation of DPW into adobe bricks, ranging from 0% to 1.5% by weight, to assess their suitability for low-cost housing construction. This includes a comprehensive examination of mechanical performance—focusing on compressive and flexural strengths—and sustainability through total absorption, capillary absorption, drying/wetting cycles, erosion, and abrasion tests.

2. MATERIALS AND EXPERIMENTAL PROTOCOLS

2.1 Material

2.1.1 Soil and crushed sand

The soil used in this research was brought from the region of Biskra (Algeria). This soil was sieved to 2 mm to eliminate clumps [5]. The chemical analysis, using the X-ray fluorescence (XRF) technique, was conducted for its characterization (Table 1). Regarding particle size analysis, tow techniques were employed, specifically sieving and sedimentometry, in accordance with Standards NF P 94-056 [34] and NF P 94 -057 [35], respectively, as clearly depicted in Figure 1. Table 2 provides an overview of certain physical characteristics of the examined soil. On the other hand, crushed sand (0/3) was used for particle size adjustment. The particle size distribution of this sand is explicitly depicted in Figure 1. The physical characteristics of the crushed sand were evaluated in accordance with the French AFNOR Standards. They are summarized in Table 2. It is worth emphasizing that the particle size distribution curves indicate that these soil characteristics are located outside the recommended limit range. For this reason, it was deemed necessary to add 30% of crushed sand in order to bring its characteristics back within the recommended limit range, as is explicitly illustrated in Figure 1.

2.1.2 Cement

In this resesrch, we utilized Portland cement CEM I with a strength class of 42.5MPa. The chemical composition and physical characteristics of this cement are presented in Tables 1 and 2 respectively.

2.1.3 Date palm waste (DPW)

The DPW aggregates used in this study come from annual palm grove maintenance activities. It is widely known that the different parts of the palm tree are renewed from one year to the next. These DPW aggregates were brought from the Technical Institute for the Development of Saharan Agronomy in the city of Biskra, Algeria (Figure 2). The results of the chemical analysis of these DPW are presented in Table 3 [36]. The size of the DPW utilized in this investigation ranges from 10 to 50 mm in length, and from 0.35 and 0.9 mm in diameter. The physical characteristics of DPW fibers are shown in Table 2 [29].

Table 1. Chemecal composition of soil and cement

Oxid	Concentration by Weight (%)	
	Soil	**Cement**
SiO_2	**34.90**	**20.27**
CaO	**26.10**	**62.40**
Al_2O_3	**6.83**	**5,32**
MgO	**2.06**	**3.35**
Fe_2O_3	**253**	**1.76**
SO_3	**0.12**	**2.26**
K_2O	**0.91**	-
Na_2O	**0.11**	-
P_2O_5	**013**	_
TiO_2	**0.34**	_
L.O.I	**24.37**	**2.70**
I.R	-	**0.64**

Table 2. Physical characteristic of soil, Crushed sand, cement, and DPW

	Soil	**Crushed Sand**	**Cement**	**DPW**
Apparent density (Kg/m^3)	**1290**	**1320**	**1410**	**101.15 [29]**
Specific density (Kg/m^3)	**2610**	**2260**	**3100**	
Specific surface from Blaine (m^2/Kg)	-	-	**351.5**	
LL (%)	**38.54**	-	-	
PL (%)	**20.4**	-	-	
PI (%)		-	-	
pH	**08.07**	-	-	
α (%)				**175 [29]**

2.2 Preparation of adobe brick samples

The proportions of soil, crushed sand and cement were kept constant throughout the study, while the percentage of date palm waste was changed as needed. Table 4 clearly presents the percentage contents of the different materials used. Adobe brick samples were then made in order to carry out our experiment. To do this, the initial sage involved elimminating moisture from the soil and crushed sand by drying them in an oven at 105℃, for 24 hours. Following this phase, the dry components (soil, sand and cement) were first homogenuously mixed for two minutes, and then, they were mixed with water using a cement mixer. Subsequently, the date palm waste (DPW) was manually introduced into the mixture, while ensuring its homogeneity. Afterward, a proportion of water equivalent to 29.5% was incorporated into the previous mixture in order to provide it with adequate plasticity which would facilitate molding. The resulting final mixture was manually introduced into cubic (10x10x10) cm^3 and prismatic (4x4x16) cm^3 molds, in three identical layers, compacted manually. These molds were then left in the open air for 72 hours to dry. After this period, the bricks were unmolded and prepared for later curing. Two curing modes were used in this study. The first one involves wrapping the bricks in plastic film and subjecting them to a laboratory curing process (MS) for 28 days, as shown in Figure 3. In the second mode of curing, the adobe brick samples are left exposed to the open air in the laboratory (AF), for the same period of 28 days, without covering them (Figure 3). Before carrying out the tests on these samples, they were dried well in an oven until their mass stabilized. It should be noted that the pyramidal bricks with dimensions (4x4x16) cm³ were exclusively used for the evaluation of the bending strength. It is useful to remember that the DPWs had previously been saturated by immersing them in water for 24 hours, before they were used.

Table 3. Chemecal composition of DPW [36]

Composition (%)	Ms	Mo	Mm	Mat	Cb	
Dry Palm (DPW)	**94,37±0,50**	**84,74±0,13**	**15,25±3,13**	**3,90±0,40**	**30,70±0,30**	
	Ndf	Adf	Cv	Hco Se	LiGn	Ci
	89,44±0,16	**65,30±0,74**	**32,83±2,31**	**23,98±2,81**	**20,45±2,36**	**12,02±0,69**

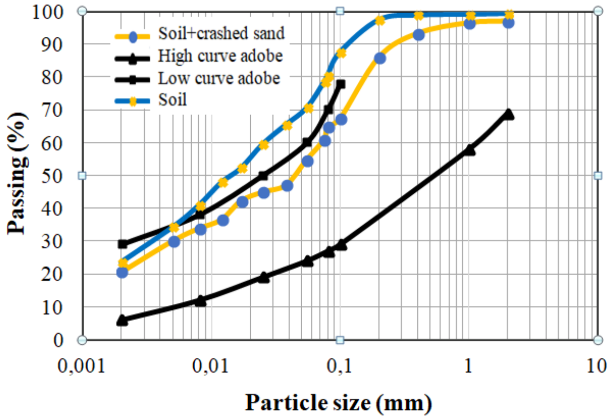

Figure 1. Particle size distribution of soil

Figure 2. Date palm wastes

2.3 Mechanical properties

2.3.1 Compressive strength

First, the maximum load to which each brick was subjected was recorded, in accordance with Standard NF

P18-406 [37] in order to evaluate the compressive strength of the adobe bricks. This strength, expressed in MPa, can be calculated using the following expression.

$$\mathrm{CS} = \frac{F_b}{S} \qquad (1)$$

where, CS is the compressive strength (MPa), F_b is the maximum rupture load (N), S is the cross-sectional area of the specimen to which the compressive force is applied. This area (mm²) is calculated from the nominal dimension of the specimen.

2.3.2 Flexural strength

After the 28-day hardening period, the adobe bricks, of dimensions (4x4x16) cm³, were subjected to three-point flexural tests, according to Standard NF P18-406 [37]. The bending strength may be calculated from the following relationship:

$$\mathrm{FS} = \frac{1.5Fl}{W^3} \qquad (2)$$

Table 4. Composition of the mixtures

Mixture	Soil (%)	Crashed Sand (%)	Cement	Water (%)	DPW (%)
	relative to the dry mixture (sand soil)		Relative to the global dry mixture		
1	**70**	**30**	**7**	**29.5**	**0**
2	**70**	**30**	**7**	**29.5**	**0.5**
3	**70**	**30**	**7**	**29.5**	**1**
4	**70**	**30**	**7**	**29.5**	**1.5**

(a) Curing mode (MS)

(b) Curing mode (AF)

Figure 3. Curing modes of adobe bricks

Here FS is the bending strength (MPa), F is the maximum load (N), l (mm) is the span length of the specimen, and W is the width.

2.4 Sustainability tests

The criteria used to assess the durability of earth bricks in the laboratory appear to be severe than the natural conditions [4]. Consequently, the durability of these materials can be studied by conducting specific tests adapted to semi-arid climates.

2.4.1 Capillary absorption

The capillary absorption of the blocks was investigated in accordance with the AFNOR XP P 13-901 Standard [38].

The water absorption coefficient (C_b) was calculated using the following equation:

$$C_b(\%) = \frac{(M_1 - M_0)}{S\sqrt{t}}\left[g/cm^2mm^{1/2}\right] \qquad (3)$$

where, C_b (%) represents the capillary absorption coefficient, M_1 (g) indicates the weight of the brick after immersion in water, M_0 (g) corresponds to the initial weight of the brick before immersion in water, S (cm²) designates the submerged surface area of the brick, and t (min) is the immersion time of the brick.

2.4.2 Total absorption

The objective of this test is to determine the total absorption (TA) of the adobe bricks. In accordance with (BS 3921 1985), there are multiple methods available to conduct this test. In our study, we have chosen the boiling test because it accurately reveals the total absorption porosity of the bricks. The TA was determined using the following formula.

$$TA\ (\%) = \frac{M_w - M_D}{M_D} \quad (4)$$

where, TA (%) is the total absorption capacity, (M_w) is the wet mass (g) and (M_D) is the wet mass (g).

2.4.3 Wetting/drying cycle test

The process followed for this test involved immersing the prepared bricks in water for 5 hours, and then drying them for 42 hours in an oven at a temperature of 71℃. This operation was repeated 12 times (12 wetting/drying cycles), and was carried out in accordance with (ASTM D559, 1989) Standard [39]. At each iteration, the bricks were brushed to eliminate small fragments of material generated by the wetting/drying cycles. The degree of wear of the specimen is quantified as a percentage of the reduction in dry weight after 12 cycles with respect to the initial weight.

2.4.4 Erosion resistance

The execution of this test followed the specification of the New Zealand Standard NZS 4298 [40]. The principle of this procedure consists of using 400 ml of water that was allowed to flow, from a height of 400 mm, onto the brick placed on a surface inclined at 30°. The custom setup, shown in Figure 4, was developed in the laboratory. It simulates raindrops. The test duration was between 20 and 30 minutes, which is within the standard range of 20 to 60 minutes. After that, the pit depth in the sample was measured by caliper in order to calculate the erodibility index. Table 5 shows the classification of the erodibility index.

2.4.5 Abrasion test

The abrasion resistance of adobe bricks was assessed in accordance with the experimental Standard AFNOR XP P 13-901 [38]. The aim is to expose the sample to friction generated by a 25 mm wide metal brush. The frequency of the movement of the brush on this exposed face is one back- and-forth movement of the brush per second, for a period of one minute, which is equivalent to 60 round trips. This experiment contributed to deriving the abrasion coefficient (C_a) of the brick.

Figure 4. Erosion test

Table 5. Class of erodibility index

Class of Erodibility Index	Depth of Pitting d (mm)	Note
3	$3 < d < 5$	erosive
4	$5 < d < 10$	Very erosive
5	> 15	Failed the test

This coefficient measures the material loss resulting from the brushing of the surface that is subjected to abrasion. It’s worth mentioning that the total steel brush mass is approximately 3 Kg. Using the above data, the abrasion coefficient (C_a) of the sample, which represents the loss of matter caused by brushing the brick on the abrasion surface, is then obtained using the formula below:

$$C_a(cm^2/g) = \frac{S}{M_0 - M_1} \quad (5)$$

where, C_a is the abrasion coefficient, S is the surface area of the brick surface subjected to abrasion, and M_0 and M_1 are respectively the masses of the brick before and after abrasion.

3. RESULTS AND DISCUSSION

3.1 Mechanical properties

3.1.1 Compressive strength

Figure 5 shows the evolution of CS as a function of DPW content and curing mode. A careful analysis of these curves shows that CS decreases as the quantity of DPW increases, for both hardening modes. A literature search revealed that voids can also form inside bricks. It was shown that this can be attributed to a remarkable decrease in the volume of waste incorporated into the mixtures when they reach a satrurated state. This decrease in volume can primarily be caused by the drying out of DPWs, which possess considerable water absorption capacity, resulting in their significant expansion. Furthermore, the compressive strength decline can be attributed to the existence of a heterogeneous microstructure resulting from the increase in pore size following the intermingling of DPWs that can often be found in various shapes and sizes [29, 41, 42]. It is worth mentioning that the CS drop in bricks with DPWs represents about 20% and 30% that of bricks without DPWs, for the MS and AF curing modes, respectively. Figure 5 explicitly shows that the CS values of bricks subjected to the MS curing mode are greater than those of bricks subjected to the AF curing mode. This result can certainly be attributed to the cement hydration process that was carried out more adequately in the MS curing mode, because in this case, as the bricks remain under cover and water does not evaporate, it can be considered that there is always an adequate amount of humidity ensuring the hydration of cement. In contrast, in the AF curing mode, water evaporates into the air, leaving insufficient water for cement hydration. It is noteworthy that the CS of the brick without DPW and subjected to MS and AF curing modes was equal to 5.5 MPa and 4 MPa, respectively. Each of the recorded CS values was discovered to be above the minimum requirement 2 MPa set by the New Mexico Standards for adobe structures [43].

3.1.2 Flexural strength

Figure 6 shows the effect of the DPW content and the curing mode on the FS of adobe bricks. Data analysis shows that the

FS increases with the DPW content. It is observed that the flexural strength increases from 0.58 MPa to 1.02 MPa. Similarly to the CS, the FS values of bricks cured by the MS mode are greater than those of bricks cured by the AF mode. It was also found that the FS of bricks with DPW was higher by 41.66% and 25.86% than those of bricks without DPW, for the MS and AF modes, respectively. The findings of this study are consistent with those previously reported by several authors. Several researchers successfully enhanced the FS of earthen bricks by introducing natural and synthetic fibers [31, 44]. These findings suggest that increasing the FS up to a certain value is certainly due to the incorporation of reinforcing fibers which absorb tensile forces, thus preventing the formation of cracks and sudden failures. This improvement in material cohesion results in higher ductility.

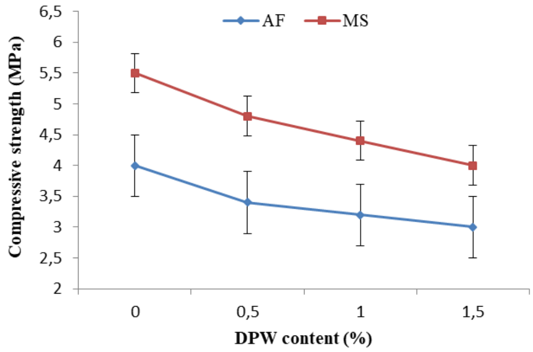

Figure 5. Variation of compressive strength with DPW content

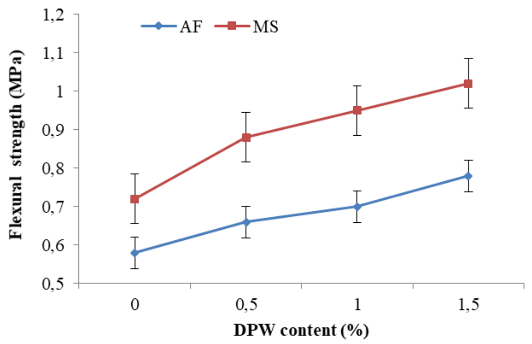

Figure 6. Variation of flexural strength with DPW content

3.2 Sustainability

3.2.1 Capillary absorption

Figure 7 illustrates the variation of the capillary absorption coefficient as a function of the DPW content, for the two curing modes. It is seen that the capillary absorption coefficient increases as the DPW content rises, for the two treatment methods. The coefficient C_b for the brick without fiber additions is equal to 12.5 $g/cm^2mm^{1/2}$ and 8.5 $g/cm^2mm^{1/2}$, for the AF and MS curing modes, respectively. However, the addition of 1.5% DPW makes the C_b coefficient increase to 16.4 $g/cm^2mm^{1/2}$ for the AF curing mode and to 12.7 $g/cm^2mm^{1/2}$ for the MS curing mode. These findings suggest that the curing method has a significant influence on the water absorption coefficient. The bricks without DPWs under the AF curing mode have an absorption coefficient C_b larger than that of the bricks without DPWs under the MS curing mode. The difference, which is estimated at 47.05%, is essentially due to the incomplete hydration of the cement in the AF mode. On the other hand, it turned out that the date palm waste has an adverse effect on the water absorption coefficient. This observation could be understood and accepted due to the significant porosity observed at the intersection of DPW pieces, and to the hydrophilic property of date palm waste (DPW) which contains cellulose and hemicellulose [23, 27, 29]. Based on the criteria defined in Standard NF XP 13-901[38], i.e. $C_b < 20$, it can be stated that all mixtures can be categorized as possessing a moderate capillarity.

3.2.2 Total absorption

The total absorption is defined as one of the parameters that affect the Sustainability of adobe bricks. It helps to determine the capacity of bricks to maintain their stability underwater without falling apart. Figure 8 depicts the variation of the total absorption of adobe bricks as a function of the DPW content, for the two curing modes. It is seen that the total absorption increases when the DPW content goes up. The total absorption values increase from 15.2% to 19.5% for the AF curing mode, while they augment from 10% to 14.6% for the MS curing mode. This increase is of the order of 31.50% and 22.05%, respectively, for the two curing modes AF and MS, in comparison with the bricks without DPW. These results align closely with those previously achieved by Boukhatem et al. [45]. These researchers have in fact demonstrated that DPWs have a strong hydrophilicity; they also showed that these fibers can absorb water up to four times their dry weight. Comparable findings have been reported in investigation curried out by other studies [29, 31]. It should be noted that the standard established by Walker [46] recommends that the total absorption capacity should not exceed 20%. Fortunately, all total absorption measurements for the adobe brick mixtures examined in the present study are below this 20% limit.

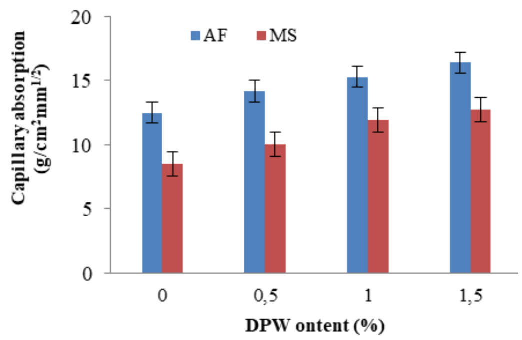

Figure 7. Variation of capillary absorption with DPW content

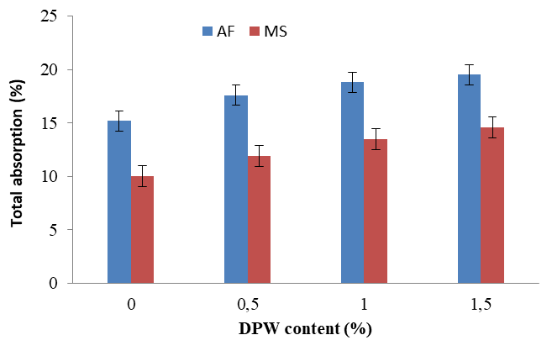

Figure 8. Variation of total absorption with DPW content

3.2.3 Wetting/drying test

Figures 9 and 10 show the influence of different percentage contents of DPW on the weight loss of adobe bricks, during each wetting/drying cycle, respectively, for the two curing modes MS and AF. It is clearly noticed that the mass loss increases, for both curing modes, as the number of wetting/drying cycles increases. However, it was noticed that the weight loss decreases as the date palm waste is added during each wetting/drying cycle. These findings are similar to those found in the study conducted by Zaidi et al. [31]. It was indeed revealed that, after twelve wetting/drying cycles, the weight losses for bricks cured with the MS curing mode decreased from 5.8% to 4.3%, while for those cured with the AF curing mode, these weight losses dropped from 9.1% to 7.2%. In percentage terms, these reductions are approximately 31.25% and 20.87%, respectively, compared to bricks without DPW. Therefore, bricks that were cured according to the AF curing mode experienced greater mass losses than those cured with the MS curing mode, as shown in Figure 11. In this context, the Brazilian Standard NBR 13553 [47] recommends a 10% limit for the mass loss of adobe bricks. The results obtained show that all bricks meet this requirement.

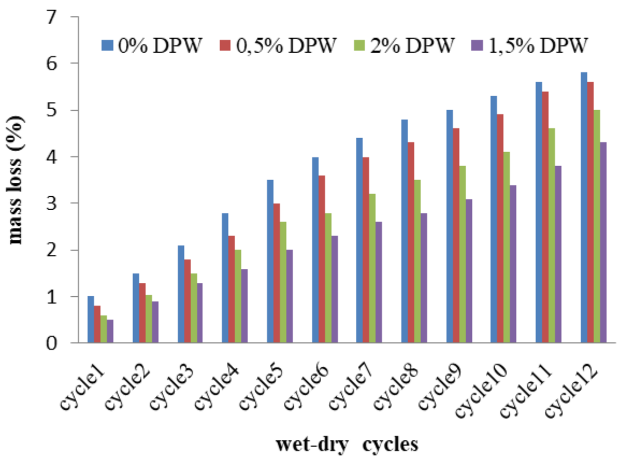

Figure 9. Variation of mass loss with DPW content (Curing mode MS)

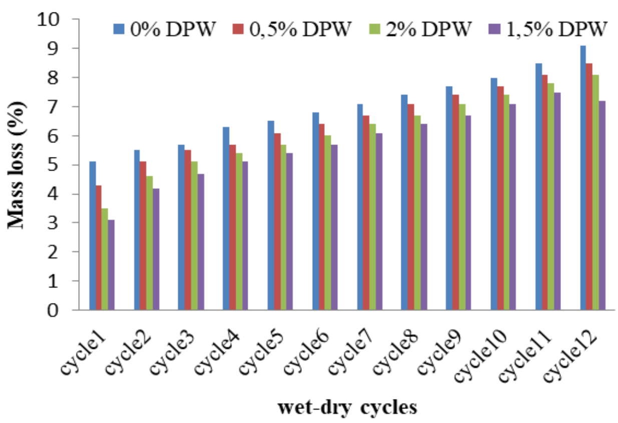

Figure 10. Variation of mass loss with DPW content (Curing mode AF)

3.2.4 Erosion resistance

Heathcote [48] pointed out that two predominant factors have a significant impact on the surface erosion extent of earthen walls, i.e. the kinetic energy of the accidental raindrops and the moisture content of the wall. When the moisture content of the wall is high, the internal cohesion of the wall material decreases, making that wall more susceptible to rainfall erosion. Consequently, for the same quantity of rainwater, an intense rain of short duration has less erosive impact than a prolonged rain. Figure 11 illustrates the variation of the erosion depth in the wall as a function of the DPW content, for the two curing modes.

The results obtained indicate that when the DPW content increases, the erosion depth decreases. Bricks without DPW have erosion depth values classified in class 3, which means that these bricks are susceptible to erosion. However, bricks containing DPW display erosion depth values lower than those defined by class 3, which allows saying that these bricks are slightly erosive. These findings highlight the fact that incorporating DPW into an earthen brick enhances its resistance to erosion, thus making it compliant with the New Zealand Standard [39] for mud brick construction (Adobe bricks).

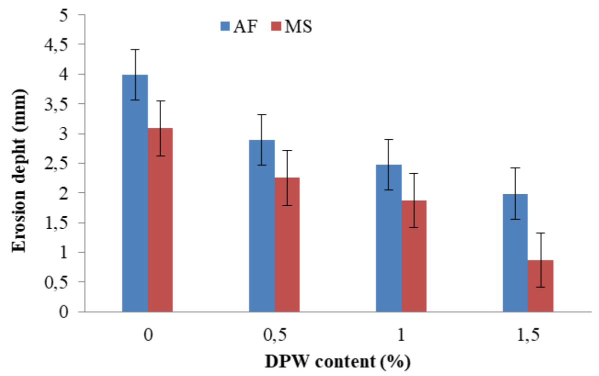

Figure 11. Variation of erosion depth with DPW content

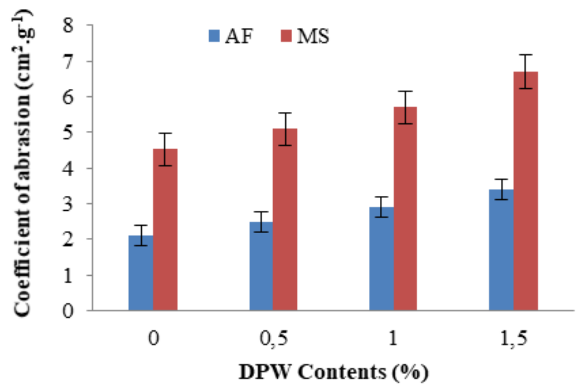

Figure 12. Variation of coefficient of abrasion with DPW content

3.2.5 Abrasion resistance

Figure 12 illustrates the variation of the abrasion resistance as a function of DPW content and curing mode. The results show the positive effect of DPW, in the two curing modes. It was found that the abrasion resistance increased by 47.90% for the AF curing mode and 61.90% for the MS curing mode, when the DPW content increased from 0% to 1.5%. This increase can be attributed to the distinct morphology of palm components. The abrasion coefficient C_a for bricks cured by the AF mode rose from 2.1 $cm^2.g^{-1}$ to 3.4 $cm^2.g^{-1}$, while that of bricks cured by the MS mode augmented from 4.43 $cm^2.g^{-1}$ to 6.7 $cm^2.g^{-1}$. It is quite obvious that the values of the abrasion coefficient C_a of the bricks cured by the AF mode are lower than those of the bricks cured by the AF mode. In addition, all the abrasion coefficient values are greater than the minimum value (2 $cm^2.g^{-1}$) recommended by Standard NF XP 13-90.

The 0.5% DPW content shows the highest resistance in compression, capillary absorption, and total absorption compared to other DPW contents. However, the 1.5% concentration provides the best results in terms of resistance to abrasion, erosion, and minimizing weight loss during wetting and drying cycles. Based on the recorded strength and durability values, adobe bricks have proven to be suitable for load-bearing walls in earthen construction.

4. CONCLUSIONS

This study focuses on the use of DPW in the production of cement-stabilized adobe bricks. The performance of the prepared samples was assessed in accordance with the minimum required various standards. Mechanical and sustainability tests were conducted to assess the properties of the adobe bricks manufactured. The results of this study allowed drawing the following conclusions:

• Bricks cured by the MS curing mode are stronger and more durable than those cured by the AF curing mode.

• Incorporation of date palm waste results in approximately 20% and 30% reduction in the compressive strength compared to bricks without DPW, for MS and AF curing modes, respectively. On the other hand, an improvement in the flexural resistance, of the order of 41.66% and 25.86%, is observed for the MS and AF curing modes, respectively.

• The adobe bricks tested, with varying DPW contents, were categorized as having low capillary in accordance with to the NF XP 13-901 Standard.

• Adding 1.5% DPW results in an increase of approximately 31.50% and 22.05% in total absorption for bricks cured using the MS and AF methods, respectively.

• A mass loss reduction, proportional to the DPW content increase, was observed after twelve wetting/drying cycles. A weight loss reduction of approximately 31.25% and 20.87% was observed for bricks containing 1.5% of DPW and hardened using the MS and AF modes, respectively. However, the erosion resistance and abrasion resistance increased as the DPW content rose. According to the New Zealand Standard criteria [39], adobe bricks containing DPW are classified as having low susceptibility to erosion. In particular, a significant improvement in abrasion resistance, of around 61.90%, was noted for bricks cured with the MS mode.

• A simple comparison of the test results with the criteria of several international Standards allowed affirming that it is possible to manufacture adobe bricks with satisfactory levels of strength and Sustainability by adding DPW to raw earth.

These conclusions highlight the importance of exploring different approaches to use date palm waste for manufacturing adobe bricks. It is therefore imperative to conduct further large-scale trials to translate the findings of this study into industrial production of earth bricks, assessing the feasibility of their manufacturing. This is one way to valorize this type of waste that is often poorly managed and can therefore be a source of environmental pollution.

Based on the results obtained, it was observed that adding fibers reduced the compressive strength while increasing the brick's absorption capacity, primarily due to a lack of adherence between the fibers and the earth matrix. It is recommended for future work to enhance this adherence by treating the fibers to optimize their bonding with the matrix.

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NOMENCLATURE

Adf	Lignocellulose
AF	Curing process in open air
Cb	Crude cellulose
Ci	Insoluble ash
Cv	True cellulose
DPW	Date palm waste
HcoSe	Hemicellulose
I.R	Insoluble residues
L.O.I	Loss on ignition
LiGn	Lignin
Mat	Total nitrogenous matter
Mm	Mineral matter
Mo	Organic matter
MS	Curing process under humid conditions
Ms	Dry matter
Ndf	Total wall
LL	Liquid limit
LP	Plastic limit
PI	Plastic index
CS	Compressive stength
FS	Flexural stength

Greek symbols

α	Absorption coefficient of date palm waste