



Date palm fibres' impact on the shrinkage and capillary water absorption of cement-stabilised earth concrete

Khedidja HIMOURI^a, Lamia GUETTATFI^a, Abdelmadjid HAMOUINE^a

^aARCHIPEL Lab, Faculty of Technology, Tahri Mohamed University of Bechar, Algeria

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ABSTRACT

Shrinkage and capillary water absorption present significant challenges to the durability of earthen buildings, undermining their structural integrity and longevity. Capillary absorption allows the soil to draw in moisture, while shrinkage leads to microcracks that weaken cohesion. These fissures create pathways for moisture ingress, exacerbating damage through repetitive cycles of expansion and contraction and further weakening the internal bonds. Thus, effective stabilisation and reinforcement using natural fibres are essential for enhancing durability and resilience. This research investigates the changes in the behaviour of cement-stabilised earth concrete concerning shrinkage and capillary water absorption, based on varying contents of date palm fibres. The main results reveal that while the incorporation of fibres positively affects shrinkage by reducing its levels, it simultaneously exhibits a negative impact on capillary water absorption by increasing the water intake of the samples, thus presenting a complex interplay between the benefits and drawbacks of fibre reinforcement.

1 Introduction

Among various phenomena, shrinkage and capillary water absorption significantly challenge the durability of earthen buildings and undermine their structural integrity. The soil's tendency to draw in water from the surrounding environment is referred to as capillary water absorption. On the other hand, as the soil matrix dehydrates, it undergoes shrinkage, resulting in the formation of microcracks that compromise the cohesion and stability of the material. These fissures not only jeopardise the durability of the structure but also act as channels for capillary water absorption, allowing moisture to infiltrate and exacerbate damage through repeated expansion and contraction cycles. This moisture ingress intensifies the material's vulnerability by weakening its internal bonds and accelerating the leaching of stabilising agents, thereby hastening erosion and structural degradation. Effective strategies, such as the incorporation of natural fibres or chemical stabilisers to mitigate these detrimental effects, are essential. Chemical stabilisation enhances moisture regulation and minimise dimensional changes, thereby fortifying the resilience and extending the lifespan of earthen constructions against both shrinkage and capillary water absorption [1,2]. However, while the presence of fibres mitigates shrinkage and microcracking [3,4], their addition can lead to increased water intake due to their high absorption capacity, ultimately exacerbating the damage [2]. This research seeks to explore the role of date palm leaf fibres as a reinforcement material for

* Corresponding author. Tel.: ++213777081866
 E-mail address: himouri.khedidja@univ-bechar.dz

cement-stabilised earth concrete, thereby addressing the existing gap in the literature by examining the impact of varying contents of date palm fibres on shrinkage and capillary water absorption.

2 Raw materials

The soil used in this study was sourced from old adobe bricks obtained from the ruined section of the ancient Ksar of Mougheul in Bechar, southwest Algeria. The bricks were crushed and subsequently sifted through a 6.3 mm sieve, after which the physical, chemical, and geotechnical properties of the resulting powder were analysed. Based on the particle size distribution analysis (NF P 94-056, NF P 94-057), this soil comprises 6.08% fine gravel, 51.32% sand, 32.38% silt and 10.22% clay. The bulk density measures 1.312 g/cm³, and the specific gravity is 2.191 g/cm³ (NF P94–053). Results from the Atterberg limits test (NF P94–051) reveal that the soil exhibits low plasticity, with a liquid limit of 19.18%, a plasticity index of 4.81%, and a clay activity of 0.47. Additionally, the soil is classified as slightly calcareous based on its carbonate content of 18.38% (NF P 94–048). Therefore, the soil can be characterised as a slightly cohesive, water-sensitive sandy loam, containing inactive clay minerals with minimal swelling potential.

The cement used is white Portland cement (C) type CEMI 52.5R, sourced from Lafarge-Algeria. Its mineralogical composition consists of 51.45% C₃S, 19.48% C₂S, 9.39% C₃A, and 0.61% C₄AF. The chemical compositions of cement as detailed in its technical sheet plus the XRF analysis of the soil are given in Table 1 [5].

Table 1 - Chemical composition of Soil and Cement

Chemical composition	Soil	Cement
CaO (%)	16	64.63
SiO ₂ (%)	52.49	22.18
Al ₂ O ₃ (%)	3.86	3.67
Fe ₂ O ₃ (%)	1.78	0.20
MgO (%)	2.01	2.3
SO ₃ (%)	0.18	2.47
K ₂ O (%)	0.93	0.66
Na ₂ O (%)	0.1	0.06
Cl (%)	0.04	0.03
LOI (%)	17.78	2.92

Date palm fibres (DP-Fibres) were extracted from the leaflets of date palm leaves. Leaflets were cut into pieces with dimensions of 30 mm in length and 7 mm in width, and subsequently immersed in water for 24 hours before being incorporated [6]. Physical, mechanical, and chemical characteristics of fibres, as indicated by previous research [7], are detailed in Table 2.

Table 2 - Date palm fibres properties

Properties	Value
Cellulose (%)	32-35.8
Hemi-cellulose (%)	24.4-28.1

Lignin (%)	26.7-28
Fats (%)	7
Absorption coefficient (%)	132
Thickness (mm)	0.55
Density (g/cm ³)	0.72
Water content (%)	53.6
Tensile strength (MPa)	93.35
Elastic Modulus (GPa)	2.67

3 Samples preparation procedure

A total of twelve mixtures were created by varying the cement dosage (0%, 3%, 6%, and 10%) and the amount of DP-Fibres (0%, 0.25%, and 0.5%). Initially, the soil was thoroughly mixed by hand with the necessary amounts of stabilisers, followed by the addition of fibres in a dry state to prevent clumping and ensure even distribution. Next, water was gradually introduced during the mixing process until a homogeneous blend was achieved. The water content was preliminarily determined using the empirical "Vicat" test, yielding values between 23.16% and 24.41% for the cement-stabilised samples, and 22.93% for the unstabilised soil samples. The resulting pastes were then poured into prismatic moulds (4×4×16cm) and compacted immediately using a vibrating table in two layers, with each layer compacted for thirty seconds. The moulds were then kept in the laboratory for five days. Finally, the specimens were carefully demoulded and stored as illustrated in Figure 1, and were labelled according to the codification outlined in Table 3.

Table 3 - Prepared blends

Blends	Code		
	0%DP-Fibres	0.25%DP-Fibres	0.5%DP-Fibres
Samples with 0% Cement	S-0S-1F	S-0S-2F	S-0S-3F
Samples with 3%Cement	S-3C-1F	S-3C-2F	S-3C-3F
Samples with 6%Cement	S-6C-1F	S-6C-2F	S-6C-3F
Samples with 10%Cement	S-10C-1F	S-10C-2F	S-10C-3F



Fig. 1 –Preparation protocol for specimens

4 Testing methods

Tests were conducted to analyse the impact of fibres on the properties of cement-stabilised earth concrete specimens, as detailed subsequently:

- Capillary water absorption test was performed according to NF-XP13-901 standard at two ages 28 and 42 days. Specimens were oven-dried, and their ($4 \times 4 \text{ cm}^2$) surfaces were subsequently immersed to a depth of 5 mm in a plastic vessel for 24 hours. The capillary water absorption rate is defined as the increase in mass of each sample after 24 hours of immersion, divided by its initial weight.
- The procedure for evaluating longitudinal shrinkage and mass loss during the drying phase is described in detail in [6]. Five days after the specimens were prepared, initial retractions were recorded, and the length changes of each demoulded sample were measured over a duration of up to 42 days. Final shrinkage ratios were then calculated based on these measurements.

5 Results and discussions

Figure 2 presents the results of the capillary water absorption test, highlighting the influence of date palm fibres on this property at 28 and 42 days. Excluding the findings related to unstabilised samples, which fell apart when in contact with water due to weak cohesion among particles and the moisture sensitivity of clay particles; these particles are prone to losing their cohesion when subjected to substantial amounts of water. The samples exhibited enhanced resistance to water absorption as the cement dosage increased. In contrast, the inclusion of date palm fibres negatively impacted this resistance, leading to an increased capillary absorption rate with higher fibre content. The growth ranges from 12.6% to 20.3% for

0.25% DP-Fibres and from 19.4% to 28.9% for 0.5% DP-Fibres at 42 days; this observation was also noted in earlier study [2]. This increase can be attributed to the high hydrophilic nature of cellulosic fibres and the micro-channels they create within the specimens, which augment water uptake. However, the water absorption capacity decreases over time for all mixtures as the cementitious hydrates gradually accumulate.

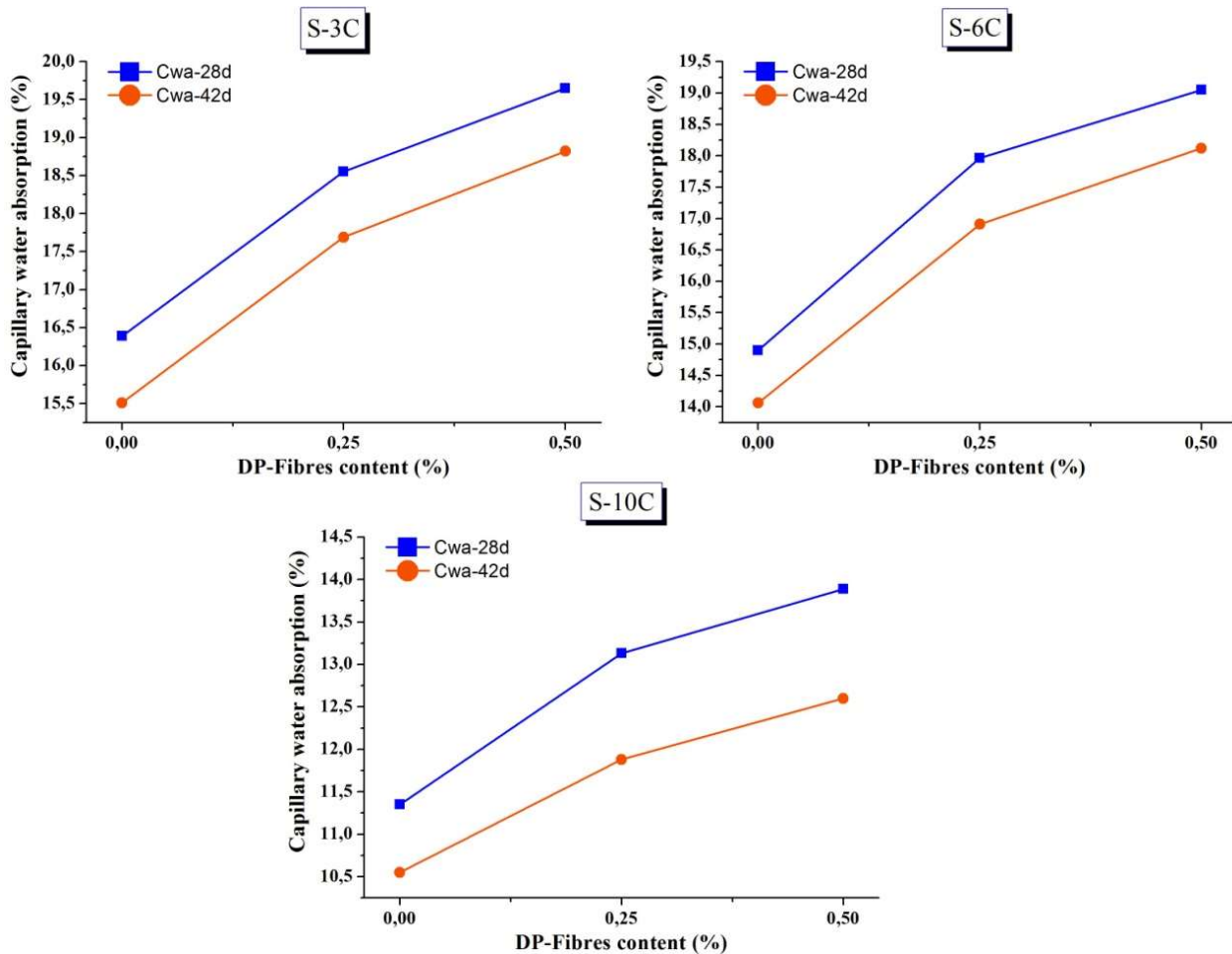


Fig. 2 –Evolution of capillary water absorption with fibres content at 28 and 42 days

The outcomes of shrinkage and mass loss during the drying phase of cement-stabilised earth concrete, relative to the DP-Fibres dosage, are illustrated in Figure 3. Unlike cement, which tends to reduce both shrinkage and mass loss, the effect of fibres on these properties appears contradictory. While incorporating fibres effectively reduces shrinkage, with even greater reductions observed at higher fibre contents, their presence simultaneously results in increased mass loss. Regarding values, the inclusion of 0.25% DP-Fibres leads to a shrinkage reduction ranging from 6.8% to 19.1% and an increase in mass loss of 6.7% to 8.6%. Meanwhile, the use of 0.5% DP-Fibres results in a shrinkage reduction between 11.6% and 26.6% while increasing mass loss by 14.2% to 22.2%. This can be attributed to the fibres' ability to resist deformation and reduce shrinkage, as well as their role in creating air channels that enhance evaporation and expedite the drying process. A similar effect of fibres on shrinkage was reported by prior work [4]. Compared to unstabilised specimens, the S-10C-3F samples, which contained 10% cement and 0.5% DP-Fibres, achieved the highest reduction in shrinkage, with a value of approximately 76.8%.

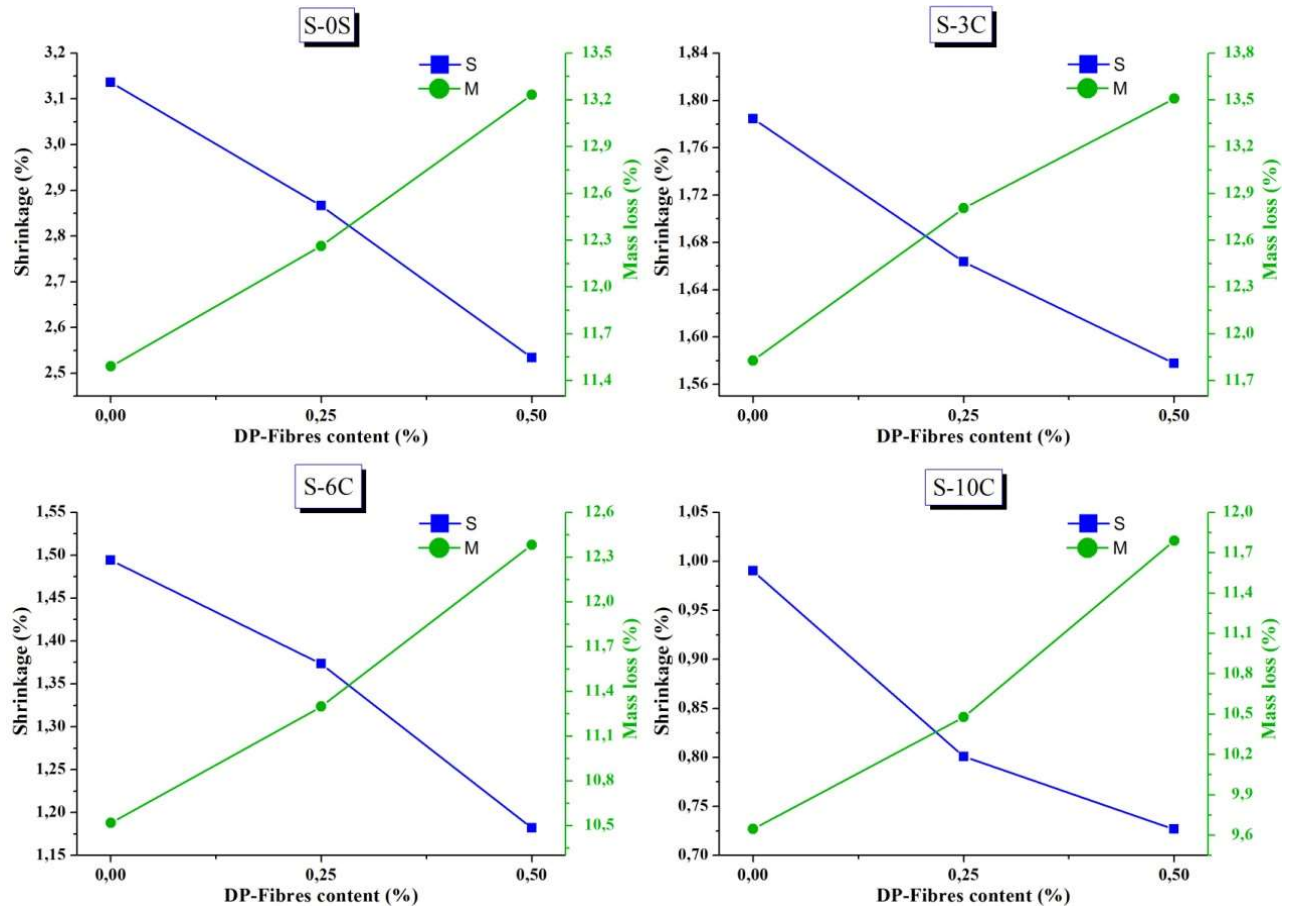


Fig. 3 –Changes in shrinkage and mass loss relative to DP-Fibre content

6 Conclusions

This study explores the effects of incorporating varying amounts of date palm leaf fibres as a reinforcement material on the shrinkage and capillary water absorption properties of cement-stabilised earth concrete samples. The main results indicate that unstabilised samples exhibit a high sensitivity to moisture. Unlike the effects of cement, the incorporation of fibres resulted in increased mass loss during the drying phase and a higher rate of capillary water absorption. However, the addition of fibres had a beneficial impact on the shrinkage of the samples, with greater reductions observed at higher fibre contents.

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