



Effect of incorporating date palm fibres on swelling behaviour and total water absorption in stabilised earth concrete

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ABSTRACT

Durability issues remain a major limitation for earthen structures, manifesting through various deteriorative phenomena. Swelling from moisture absorption leads to dimensional changes and cracks, while prolonged water exposure causes softening, reducing cohesion and accelerating structural deterioration. These issues are particularly severe in areas with fluctuating humidity or heavy rainfall, emphasizing the importance of stabilisation techniques and fibre reinforcement to improve the longevity and resilience of earth buildings. This study examines the effect of incorporating varying amounts of date palm fibres as reinforcement on the swelling and total water absorption of stabilised earth concrete samples. The main findings indicate that, contrary to the effects of stabilisers, the addition of fibres negatively impacts both swelling and total water absorption. This makes the earth concrete specimens more susceptible to water absorption, swelling, and the development of cracks.

1 Introduction

Durability challenges remain the primary limitation in earthen structures, manifesting through various deteriorative phenomena. Notably, swelling and water absorption cause significant degradation, severely compromising the performance and longevity of these buildings. Swelling occurs due to moisture absorption, causing dimensional changes that can lead to cracks and structural damage, while softening results from prolonged water exposure, reducing material cohesion and weakening the structure, further accelerating deterioration over time. These issues are particularly pronounced in regions with fluctuating humidity or heavy rainfall, underscoring the need for effective stabilisation techniques, and incorporating reinforcing materials, such as fibres to enhance the performance and longevity of earth buildings. In response to these challenges, research highlights the potential of using plant fibres. These fibres are valued for their biodegradable and eco-friendly properties, helping to enhance tensile strength and reduce crack propagation [1,2], improve the resistance to immersion based on the values of wet to dry compressive strength ratio [3], and reduce swelling [4]. However, some studies have shown that fibres incorporation can increase the water absorption of earth blocks, thereby exacerbating swelling and moisture-related damage [5]; as the incorporation of fibres into earth blocks can create more porous structures, allowing higher moisture intake, which may counteract some of the stabilisation effects. This study, aims to evaluate the viability of date palm leaf fibres as a reinforcement material for earthen structures, by examining the impact of

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incorporating different contents of these fibres on the swelling and total water absorption behaviour of stabilised earth concrete samples.

2 Materials and methods

2.1 Materials

The soil was derived from old adobe bricks, which were gathered from the collapsed part of the ancient Ksar of Mougheul located in Bechar, southwest Algeria. The blocks were crushed and then screened through a 6.3 mm sieve, after that the physical, chemical and geotechnical characteristics of the powder were analysed. The grain size distribution (NF P 94-056, NF P 94-057) shows that the soil includes 10.22% clay, 32.38% silt, 51.32% sand and 6.08% fine gravel. Its bulk density is 1.312 g/cm³ and its specific gravity is 2.191 g/cm³ (NF P94-053). Based on the results of Atterberg limits test (NF P94-051), the soil has a low plasticity with a liquid limit of 19.18%, a plasticity index of 4.81%, and a clay activity of 0.47, and that it is considered as slightly calcareous material according to its carbonate content of 18.38% (NF P 94-048). Thus, our soil is a slightly cohesive, water-sensitive sandy loam, which contains inactive clay minerals with low swelling potential.

The utilised lime is quicklime (Q) from SARL BMSD-Chaux-Saida, with a bulk density of 0.78 g/cm³ and a specific gravity of 2.6 g/cm³. The utilised cement is white Portland cement (C) type CEMI 52.5R from Lafarge-Algeria. Its mineralogical composition includes 51.45% C₃S, 19.48% C₂S, 9.39% C₃A, and 0.61% C₄AF. The chemical compositions of stabilisers as detailed in their technical sheets plus the XRF analysis of the soil are given in Table 1 [6].

Table 1 - Chemical composition of Soil, Quicklime and Cement

Chemical composition	Soil	Quicklime	Cement
CaO (%)	16	96.83	64.63
SiO ₂ (%)	52.49	1.259	22.18
Al ₂ O ₃ (%)	3.86	0.27	3.67
Fe ₂ O ₃ (%)	1.78	1.165	0.20
MgO (%)	2.01	1.28	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
Mn ₃ O ₄ (%)	-	0.0019	-
Reactivity T60	-	< 2 min	-
LOI (%)	17.78	-	2.92

Date palm fibres (DP-Fibres) were sourced from the leaflets of date palm leaves. Leaflets were chopped into pieces measuring 30 mm in length and 7 mm in width, and then soaked in water for 24 hours prior to incorporation. Physical, mechanical, and chemical properties of the fibres, as determined by prior study [7], are summarised in Table 2.

Table 2 - Date palm fibres characteristics

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

2.2 Preparation of specimens

Twenty-one mixtures were prepared, by varying the dosage of cement (0, 3, 6, 10%), quicklime (0, 3, 6, 10%) and DP-Fibres (0, 0.25, 0.5%). At first, the soil was thoroughly and manually mixed with the required amounts of stabilisers, then with adding fibres in a dry state to prevent fibres from intermingling and forming clumps. Subsequently, the sufficient amount of water was gradually added during mixing until a homogeneous mixture was achieved. Water content was assessed preliminarily by the empirical “Vicat” test as detailed in [8], with values in the range of 23.16-24.41% for cement-specimens and 24.52-26.37% for quicklime-specimens and 22.93% for unstabilised soil specimens. After that, the pastes was poured in prismatic moulds (4×4×16cm), and compacted immediately using a vibrating table in two layers (thirty seconds each layer). The moulds were conserved in the laboratory for five days. Finally, the specimens were carefully demoulded and stored as shown in Figure 1. The samples were labelled according to the codification specified in Table 3.

Table 3 - Prepared mixtures

Mixtures	Code		
	0%DP-Fibres	0.25%DP-Fibres	0.5%DP-Fibres
Samples with 0%Stabiliser	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
Samples with 3%Quicklime	S-3Q-1F	S-3Q-2F	S-3Q-3F
Samples with 6%Quicklime	S-6Q-1F	S-6Q-2F	S-6Q-3F
Samples with 10%Quicklime	S-10Q-1F	S-10Q-2F	S-10Q-3F

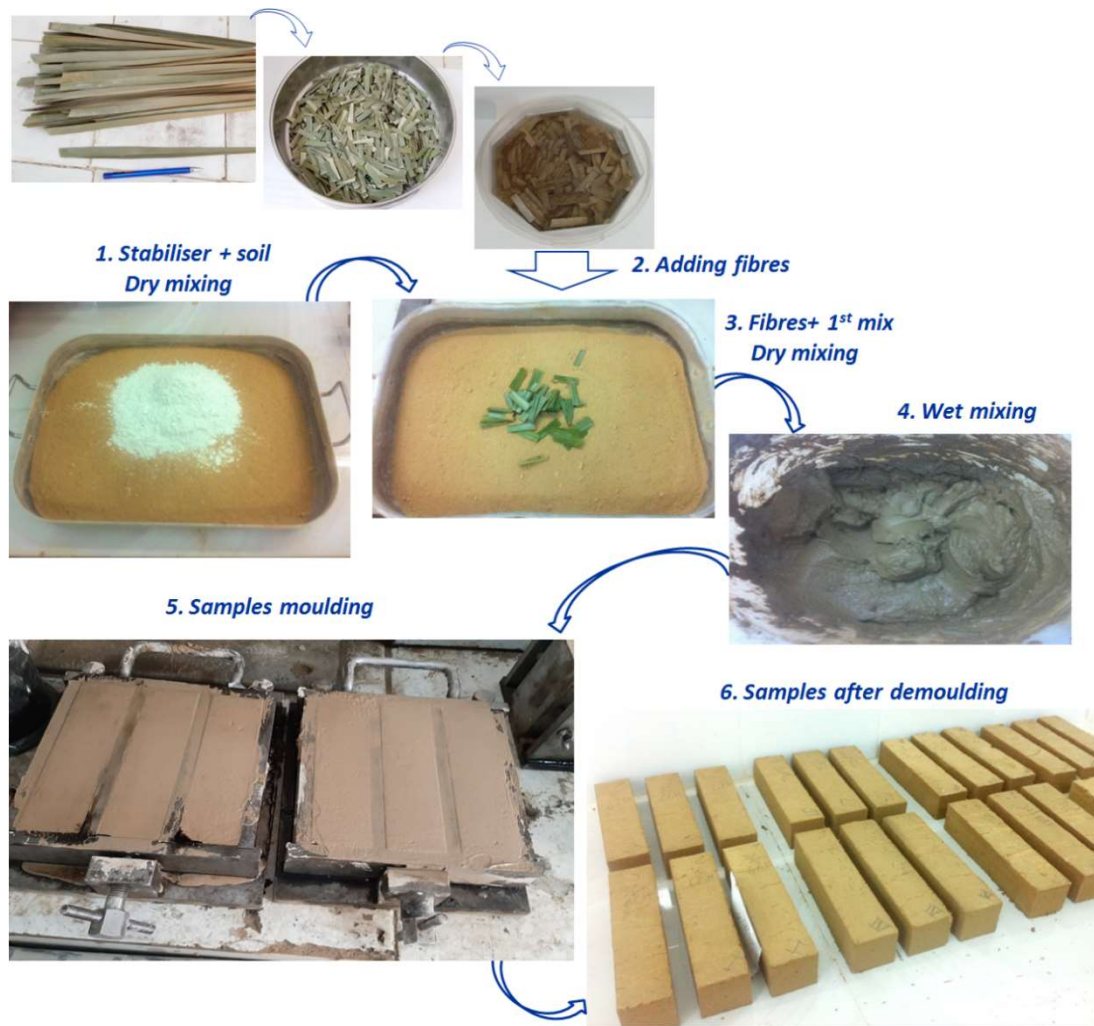


Fig. 1 –Process for specimen preparation

2.3 Tests

The tests were performed to evaluate the effect of fibres on the characteristics of earth specimens at two ages 28 and 42 days, as outlined below:

- Total water absorption was determined by submerging the oven-dried specimens in a water tank for different durations; after 24, 48, 72 and 96 hours, the wet specimens were weighed, and the total absorption was calculated by dividing the gain in mass per sample initial weight.
- Swelling test was performed according to the XP P13-901 standard. Prior to testing, two measuring studs were sealed on each sample using an epoxy resin and the initial measurements (l_0) were taken. Subsequently, samples were soaked in a water trunk for 96 hours. The specimens were then removed from water and drained for 10 minutes, and the after-immersion distance between studs (l_{96}) was measured. Linear expansion degree was determined by dividing the change in distance between studs ($l_{96}-l_0$) per initial distance (l_0).

3 Results and discussions

The outcomes of water absorption by full immersion of earth concrete after 24, 48, 72 and 96 hours are depicted in Figure 2; except for the mixtures S-0S, S-3C and S-3Q, which collapsed after 24h of submersion. This softening behaviour is attributed to their low particles cohesion underwater, as clay particles lose their cohesion when exposed to a significant amount of water in and the lack in stabiliser content which means lack in pozzolanic cohesions and the soil remains water-sensitive. Thus, this test is useful as an indicator for the stabiliser dosage efficiency and the durability of earth bricks

against water. Quicklime samples absorb less water compared to those with cement, yet the increase in both stabilisers content reduces water absorption. Unlike binders' impact, adding DP-Fibres negatively affected the total water absorption capacity, which also increased with the increase in fibres dosage, in the range of 5.2% to 9.7% for 0.25% DP-Fibres and 8% to 15.8% for 0.5% DP-Fibres, at the age of 42 days; the same remark was pointed out by prior study [5]. This augmentation is ascribed to the high hydrophilic capacity of cellulosic fibres and the micro-channels they establish within the specimens, facilitating increased water uptake. Nonetheless, the water absorption capacity diminishes with ageing across all mixtures due to the progressive accumulation of cementitious phases. Walker and Standards Australia specify that total absorption after 24 hours of submersion should be less than 20%; the resulting values are within this limit, except for S-6C-3F at 28 days.

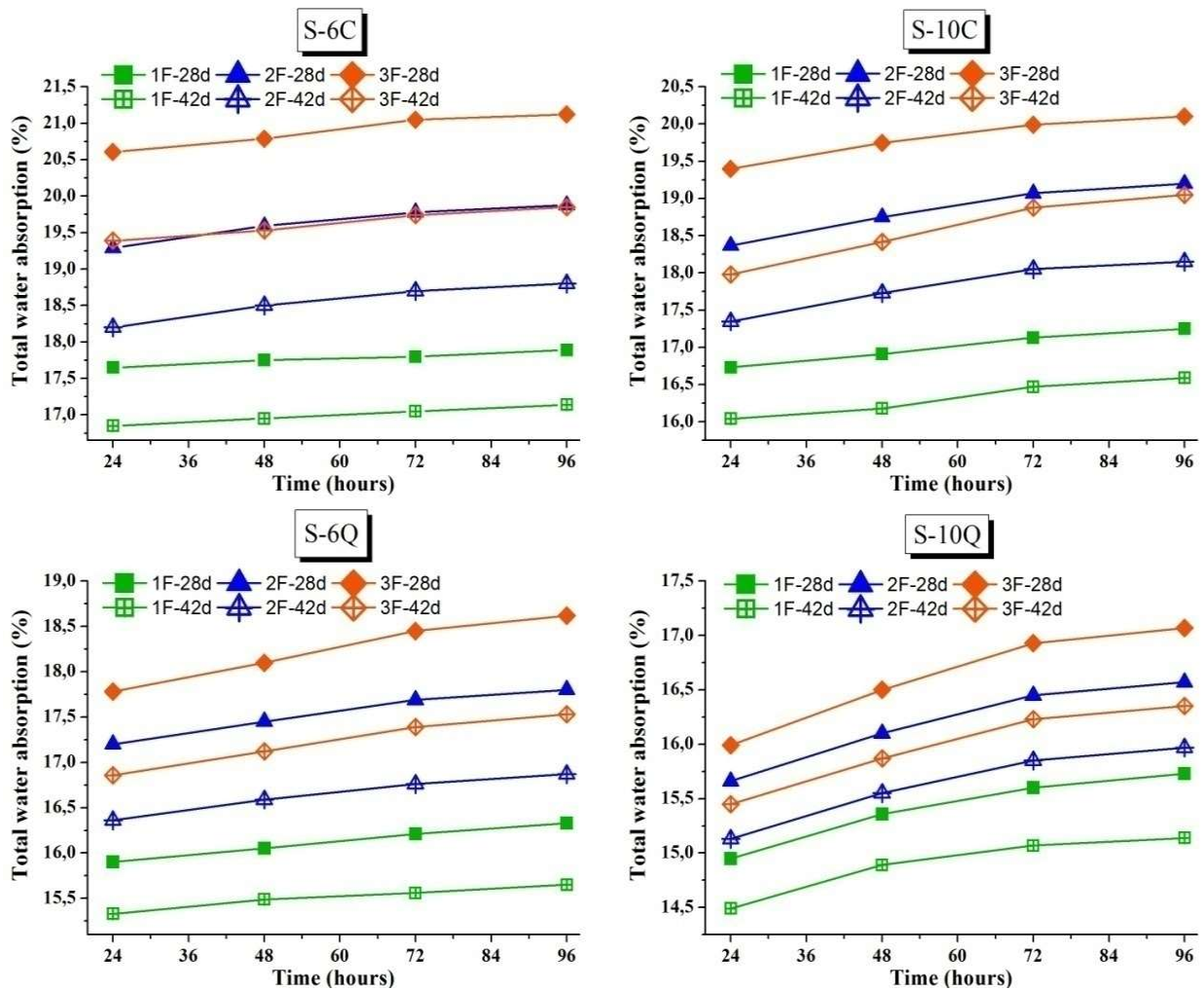


Fig. 2 –Changes in total absorption with fibres content over time at 28 and 42 days

Figure 3 illustrates the influence of fibres on the swelling behaviour of earth concrete specimens that withstood 96 hours of submersion. In contrast to water absorption, cement-earth concretes gave lower swelling values than quicklime-earth concretes, which can be explained in accordance with the compressive strength results reported in [6] and may be attributed to the difference between the required periods for stabilisers to form cementitious products. Linear expansion decreased with age as well for all mixes due to the development of new hydrates. Swelling diminished with the increase in cement and quicklime; however, analogous to water absorption, the incorporation and escalation of fibre content intensified the degree of swelling. These findings are congruent with previous research [5]. In terms of values, the augment in swelling at the age of 42 days was in the range of 33.3-50% and 66.7-80% for the addition of 0.25% DP-Fibres and 0.5% DP-Fibres, respectively.

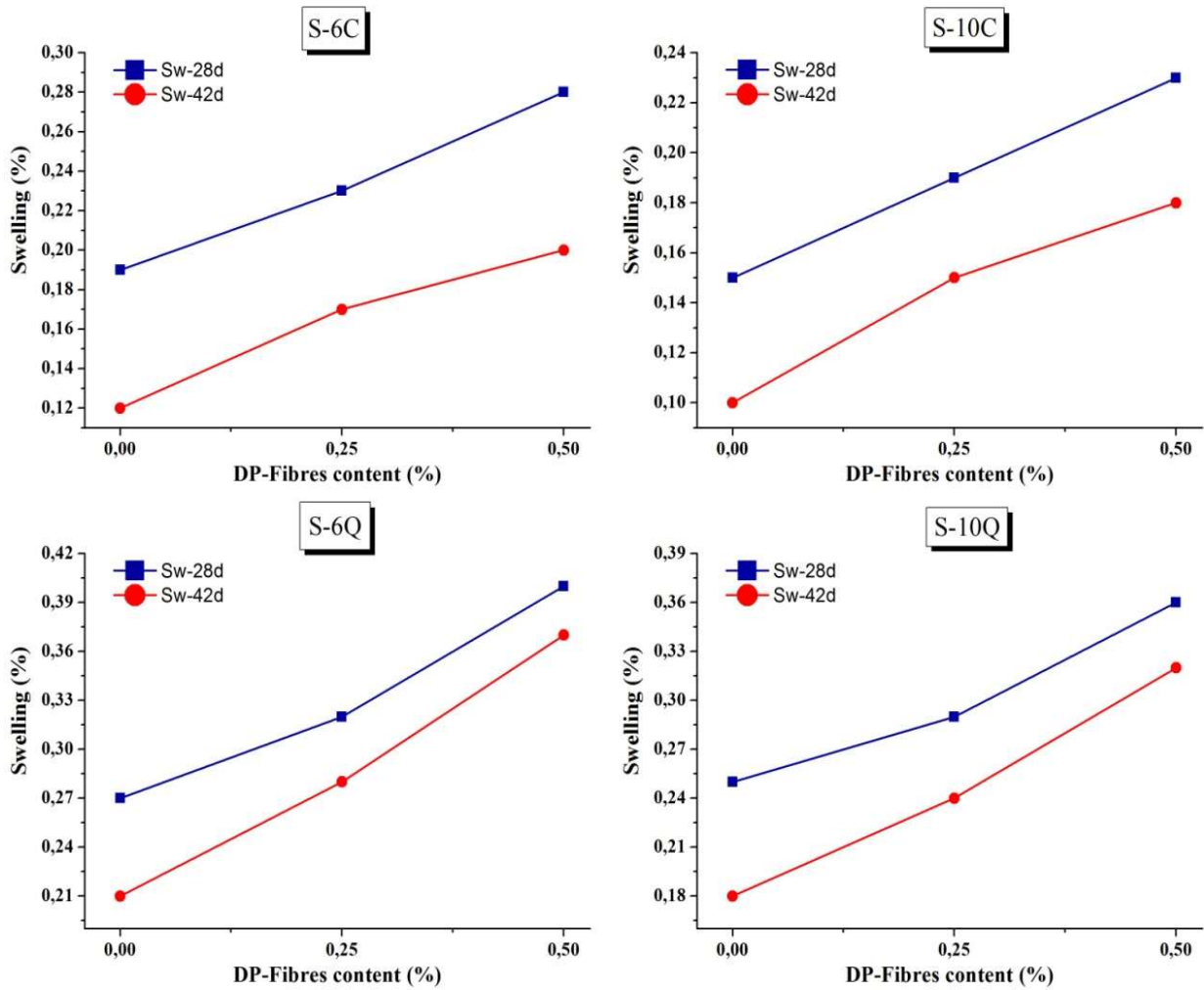


Fig. 3 –Variation in swelling based on DP-fibres content at 28 and 42 days

4 Conclusions

This study investigates the impact of incorporating date palm leaf fibres as a reinforcement material at varying contents on the swelling and total water absorption behaviour of stabilised earth concrete samples. The key findings reveal that samples with 3% stabilisers exhibited softening behaviour and collapsed upon submersion in water. Cement provided greater improvements compared to quicklime concerning swelling, whereas quicklime offered better enhancements for total absorption. However, the presence of DP-Fibres had a negative impact on both swelling and total water absorption.

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