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Development and Characterization of Stabilized Earth Blocks Based on Recycled Sediment and Lightweight Aggregates

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Abstract: The main objective of this experimental study is the development of eco-materials based on recycled material by recovery of dam sediment, and the incorporation of lightweight aggregates in order to improve the physical, mechanical and thermal properties of the stabilized earth blocks (SEB) used in construction. The development of stabilized earth blocks is carried out using different amounts of stabilizers (cement, lime) and different dosages of lightweight aggregates in substitution of dam sediment (10, 20, 40 and 50%). An experimental campaign was directed to test the physical, mechanical and thermal characteristics of the blocks produced. The obtained results show that the blocks made from 50% lightweight aggregates and 10% stabilizer (cement) have the best performances. Adding lightweight aggregates to the block composition improves shrinkage. Using a higher percentage of lightweight aggregates and combined to a fixed quantity of binder leads to better stability of the earth blocks by reducing weight loss and increasing durability.

Keywords: Earth block, Recycled sediment, Strength, Thermal conductivity, Lightweight aggregates

Introduction

Stabilized earth blocks (SET) are considere an interesting option for durable, comfortable and economical construction. Although criticized for its sensitivity to water and lack of durability, this material has many advantages when used appropriately, such as low energy consumption during its production, its aesthetic qualities and its thermal inertia. The use of stabilizers such as cement or lime and other materials such as fibers in stabilizing the earth in general is a fairly well known field thanks to significant research work, which has made it possible to understand the mechanisms of reactions between the earth and these stabilizers, and their effects on the properties of the earth.The compaction and/or incorporation of granulates or fibers can affect the mechanical and/or thermal performances due to their physico-mechanical effects in the earthen matrix. However, this approach does not necessarily guarantee the earthen material to resist in contact with liquid water (Bruno et al., 2017). Furthermore, the recycling and recovery of waste and by-products in the field of construction can also contribute to solving the ecological and environmental problems linked to the rejection of these materials, which offers interesting perspectives for sustainable and economical construction.

Masuka et al. (2018) used coal fly ash, lime, and wood aggregates for the production of earth blocks. The authors reported comparable or even higher dry compressive strength than cement stabilized blocks, but

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deplored the necessity of little (4%) cement content for better-wet strength. Hakimi et al. (1998) studies the thermo-physical properties of the earth, stabilized with cement contents ranging from 0 to 10% (0%, 4%, 5%, 5%, 8%, and 10%).The obtained results reveals that the thermal parameters evolved considerably with the water content for raw earth, (0% cement) and cement. Ouedraogo et al. (2015) carried out an experimental study on the mechanical and thermophysical characteristics of compressed earth blocks, stabilized using paper (cellulose) and/or cement. The results indicated a significant improvement in the properties of the earth blocks following stabilization, and the incorporation of paper into the earth-cement mixture had a less pronounced impact on the mechanical strengths. However, this addition made it possible to achieve even higher performances than those observed with raw earth. Gueffaf, et al. (2020) conducted a study to assess the feasibility of recycling dam sediments for the manufacture of stabilized blocks. For elaborated samples, different percentages of cement and lime were chose respectively (0, 6, 8, 10 and 15%), (0, 5, 8 and 10%). The results showed that blocks made from dam sediments could have an improved compressive strength of 172% at 15% cement and 85% at 10% lime. The thermal conductivity is also improve, with a value of 1.06 W/m.k at 15% cement and 0.73 W/m.k at 10% lime.

Several work has been carried out on improving the thermal properties of earth blocks by incorporating lightweight aggregates such as in the work of Layachi et al. (2023) which examines the impact of the incorporation of expanded polystyrene (EPS) on the thermal, mechanical and environmental properties of lightweight earth blocks (LWB). The blocks were manufacture with different percentages of EPS (from 0% to 65%) and were subject to extensive characterization, including thermal properties such as conductivity, diffusivity and heat capacity, mechanical properties such as flexure and compression, as well as environmental life cycle assessment. The results indicate a significant improvement in thermal insulation with the increase in the percentage of EPS, although this is accompanying by a reduction in mechanical resistance. The addition of EPS also improved the ductility of LWBs. Environmentally, the use of LWBs with 65% EPS showed a notable reduction in the energy required and CO_2 emissions compared to conventional walls, thus highlighting that the incorporation of EPS in LWBs presents a strategic promising for increasing the energy efficiency of buildings. The objective of this work is the optimization of the formulation of eco-materials based on recycled dam sediment, lightweight aggregates and stabilizer in order to improve the physical, mechanical, thermal properties and the durability of earth blocks.

Material Used

Sediment

The sediment used in this experimental work comes from the KEDDARA dam located in BOUMERDES city, 8 km south of BOUDOUAOU and 35km east from Algiers the capital with a capacity of 142,391 Hm^3 is supplied by contributions from the Keddara Oueds.

Figure 1. Keddara dam: Sampling sites

Chemical Composition

The chemical analysis of the kaddara sediment was carried out by X-ray fluorescence according to standard NF P 15-467 (Table 1). Sediment is essentially formed of oxides of silicon SiO2 and aluminum Al_2O_3 that are the majority oxides, an acceptable content of Fe_2O_3 of CaO, K2O and MgO, this material is also made up of TiO2, Na_2O, SO_3, MnO and P_2O_5 with a small amount. The SiO_2/Al_2O_3 mass ratio of our sediment is 2.92.

Table 1. Chemical composition of sediment

Constituant	SiO2	Al2O3	Fe2O3	CaO	K2O	MgO	TiO2	Na2O	SO3	MnO	P2O5
% Massique	58.5	20.0	7.46	5.85	3.91	2.05	0.852	0.638	0.343	0.149	0.122

Mineralogical Analysis

The mineralogical analysis of the sediment was carried out by X-ray diffraction, which gives us an idea of the main crystalline minerals by the existence of the characterizing lines.

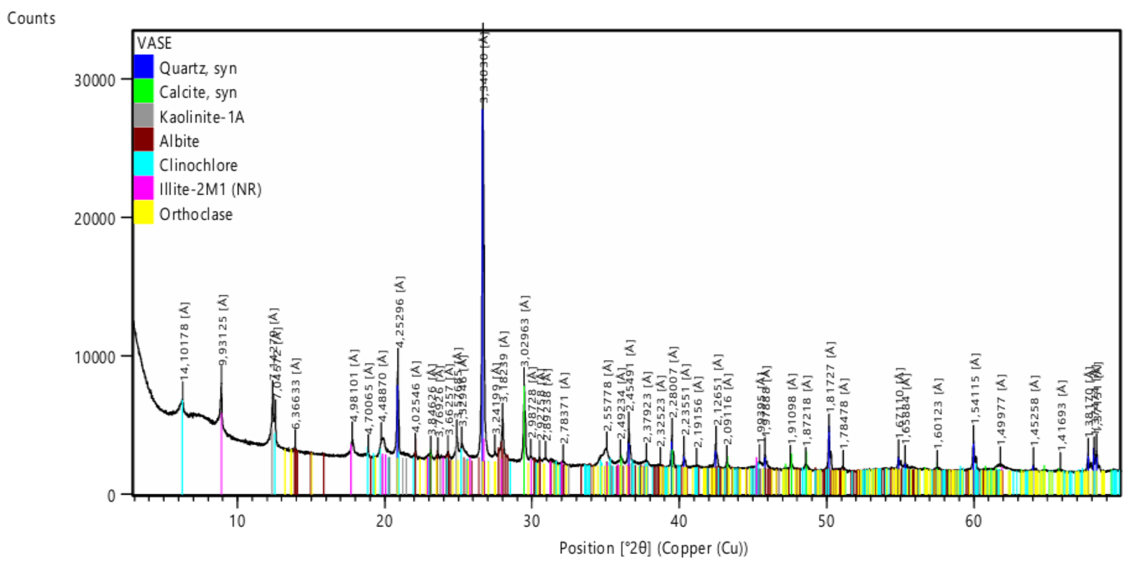

Figure 2. Mineralogical analysis of the sediment used

The Figure 2 indicates the presence of Quartz (SiO2) with significant peaks, followed by calcite ($CaCO_3$) and a good proportion of Alumina (AL_2O_3) represented as Kaolinite (AL_2O_3 $2SiO_2$ $2H_2O$) and illite, clinochlore, albite (NaAl Si_3O_8) and orthoclase are in low proportions.

Liquidity Limit

The test is carried out by the falling cone method and plasticity limit: NF EN ISO 17892-12 (June 2018). The obtained results are shows in Table 2. The obtained results in table 2 shows that the limits of plasticity are acceptable but sediment contain too many fines particles for compressed earth blocks (XP P 13-901 standard).

Table 2. Liquidity and plasticity limit

Material	W_L (%)	W_P (%)	I_P (%)
Sediment	42	23	19

Lightweight Aggregate

Lightweight aggregate used in this work is sand with a low density compared to traditional aggregates. It is made from expanded clay. The Granulometric analysis of Lightweight sand is realized according to EN 933-1 standard and indicates that is classified as 0/3. Technical sheet of Lightweight sand are presented in table 3.

Table 3. Technical sheet of lightweight sand

Testing and standards	**Results**
Bulk density EN 1097-3	1074 Kg/m^3
real density EN 1097-6	1730 Kg/m^3
Fine content EN 933-1	2.06%
Sand equivalent NF EN 933-8	94
Fineness modulus EN 12620	3.22
Water absorption (5’) EN 1097-6	8,24%
Water absorption (30’) EN 1097-6	10,96%
Water absorption (24 h) EN 1097-6	15,00%

Cement

In this work we used a Portland cement composed CEM II / B-L 42.5 N according to the NF EN 197-1 standard. Technical characteristics of cement are presented in Table 4.

Table 4. Technical characteristics of cement

Testing	**Results**
Loss on ignition (%) (NA5042)	10.0±2
Sulphate content (SO3) (%)	2.5±0.5
Magnesium oxide content MgO (%)	1.7±0.5
Chloride content (NA5042) (%)	0.02-0.05
C3S (%)	60±3
C3A (%)	7.5±1
Normal Consistency (%)	26.5±2.0
Fineness according to the Blaine method (cm2/g) (NA231)	3700-5200
Shrinkage at 28 days (µm/m)	<1000
Expansion (mm)	≤3.0
Start of setting (min)	150±30
End of setting (min)	230±50
Compressive strength 28 days (MPa)	≥42.5

Lime

Lime used is air lime; it is a white powder with a maximum grain size of 90 µm, having a high CaO content (greater than 73%). It has a specific density of $2g/cm^3$.

Earth Block Production Process

After treatment and driying of the sediments, it was crushed and finally passed through a 5 mm sieve to eliminate the large lumps. According to (Mahdad et al, 2018).The compaction of the blocks was achieved by using a hydraulic semi automatic press with a compaction pressure of 7 MPa and the dimensions of the tested blocks are 295 mm of length, 140 mm of width and 90 mm of height. Two binders and different dosages of lightweight sand were used cement with different contents: 0%, 2.5%, 5%, 7.5% and 10% and lime of percentages:0%, 5%, and 10%. Lightweight sand is introduced in blocks at differents dosages 10%, 20%, 40% and 50%. The required testing age for sediment/cement blocks is 28 days when 90 days are necessary for sediment /lime (Rigassi, 1995). The earth blocks sample production process is represented in Figure 3.

Results and Discussions

Several tests were carried out on the stabilized earth blocks. The production of more than 200 stabilized earth blocks allowed us to obtain results that are more representative and to present several observations. Experimental tests carried out on earth blocks allow the evaluation of different characteristics and performances of the blocks. For all tests, the following designations are adopted:
S: sediment, C: cement, L: lime, LS: lightweight sand

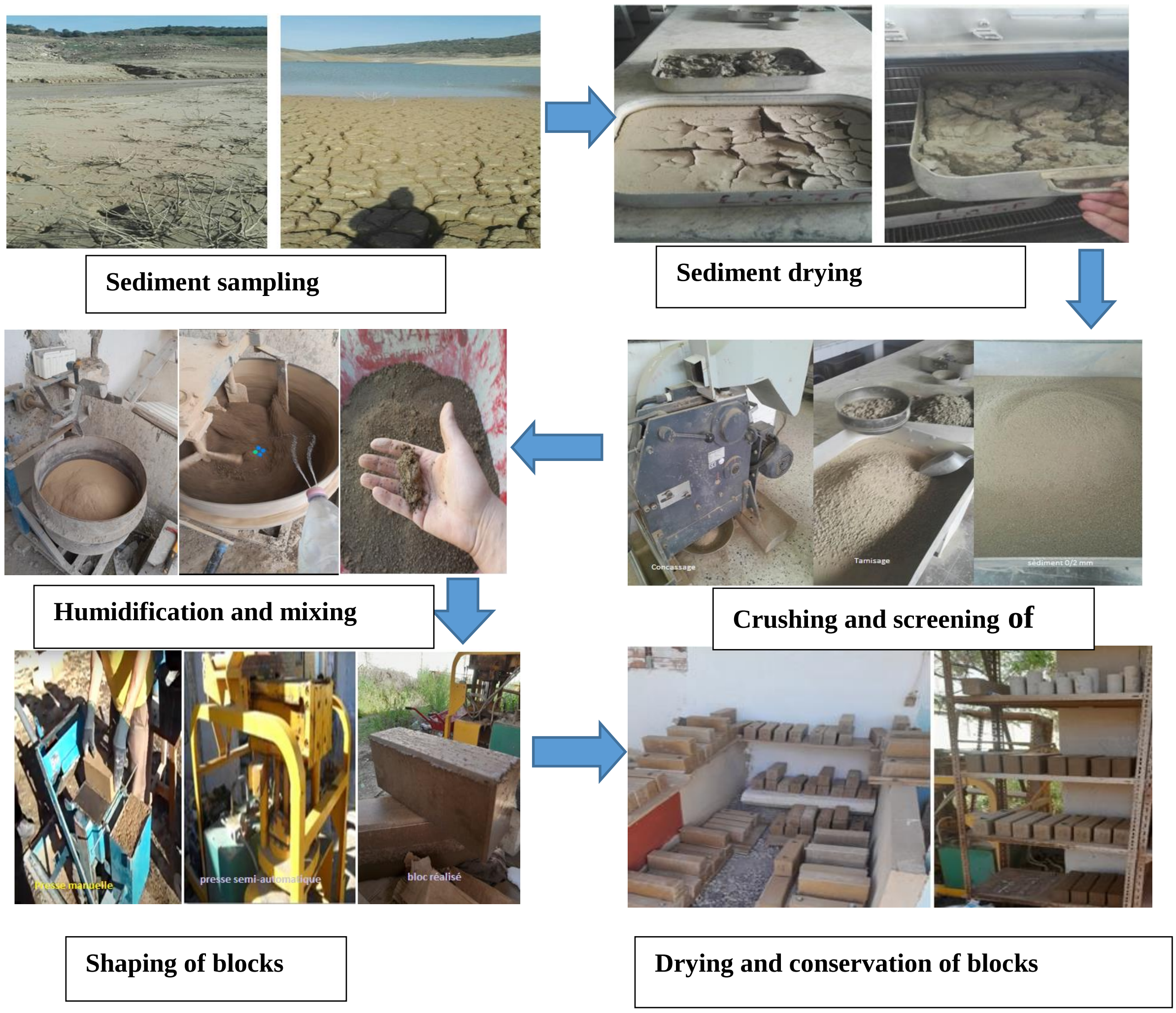

Figure 3. Earth blocks sample production process

Shrinkage Test

The drying shrinkage test of earth blocks according to standards XP P13-901. The results of the shrinkage tests carried out on the earth blocks prepared using sediment and stabilizers with different dosages of lightweight sand are illustrate in Figures 4 and 5.

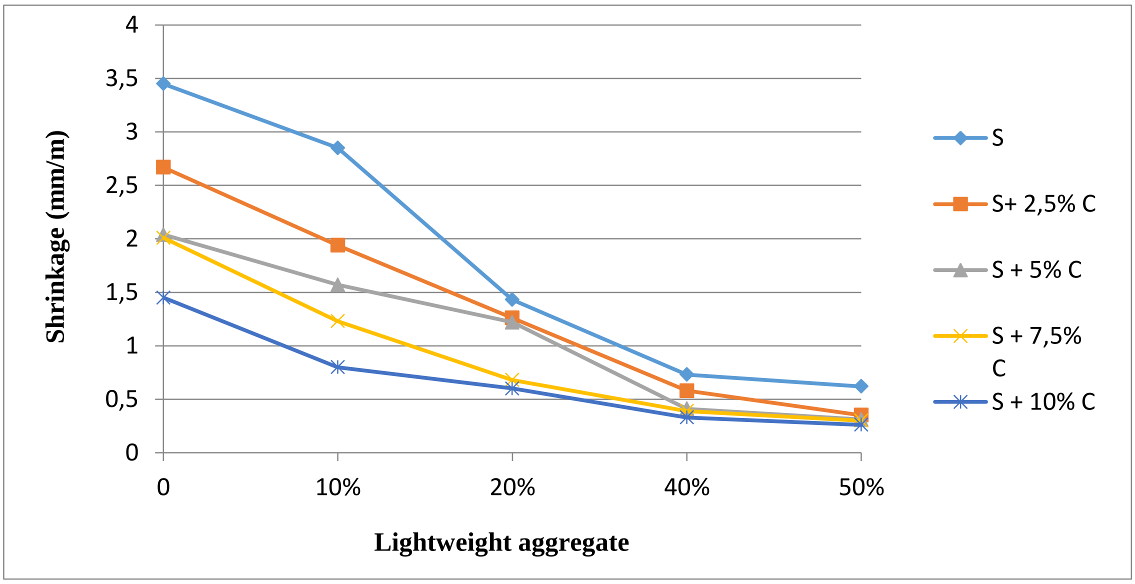

Figure 4. Shrinkage test for blocks based on Cement

The results show that the shrinkage decreases with the increase in the percentage of lightweight sand. The blocks of stabilized earth made by sediment with 40% and 50% light sand stabilized by cement 7.5% and 10% presenting less shrinkage compared to the blocks stabilized earth by sediment only and sediment with 10% and 20% light sand stabilized by cement 2.5% and 5%. The blocks stabilized with 40% and 50% of light sand, stabilized by lime at 5% and 10%, exhibited less shrinkage compared to the blocks stabilized by sediment only and sediment with 10% and 20% of light sand stabilized by lime 5% and 10%. The addition of lightweight sand to the composition of the stabilized earth blocks seems to improve their shrinkage properties. In addition, stabilization with lime or cement seems to reinforce this positive effect.

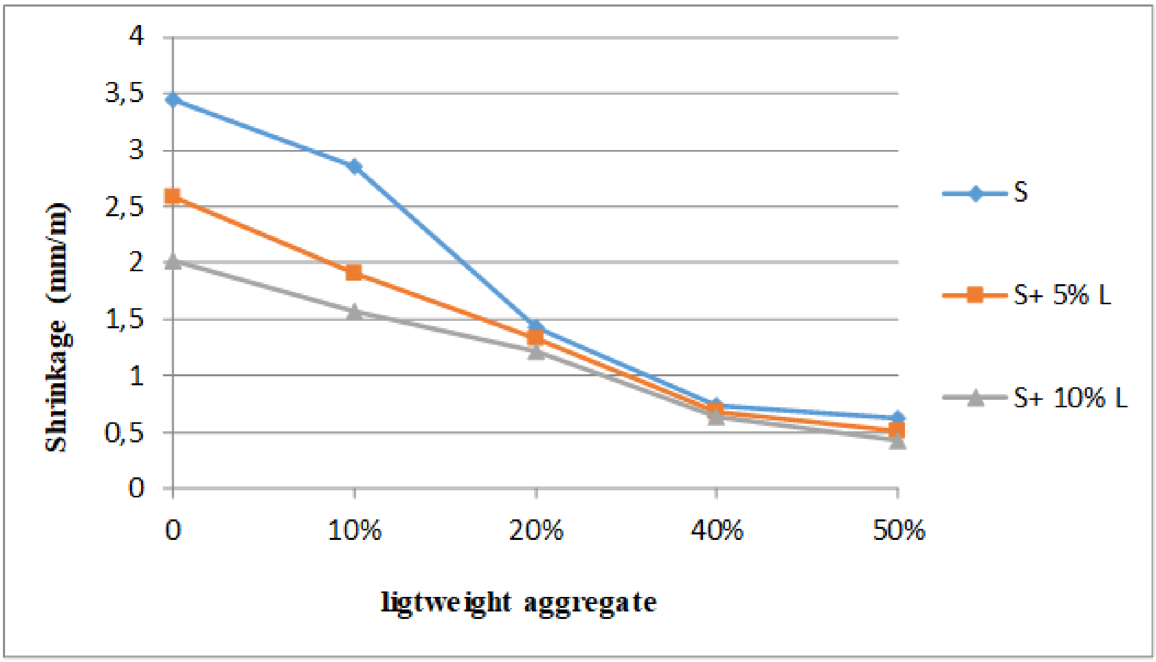

Figure 5. Shrinkage test for blocks based on lime

Water Absorption Test

The water absorption test consists in determining the water content absorbed by capillarity in compressed earth block. Before being immersed, the sample was weighted with an accuracy of 2g; then the lower face of the sample was immersed in a water bath to a depth of 5 mm and left for 10 min according to STANDARD XP

P13-901. The results of water absorption in the partial immersion test for blocks with different dosages of lightweight sand and stabilizer (cement, lime) are show in Figure 6.

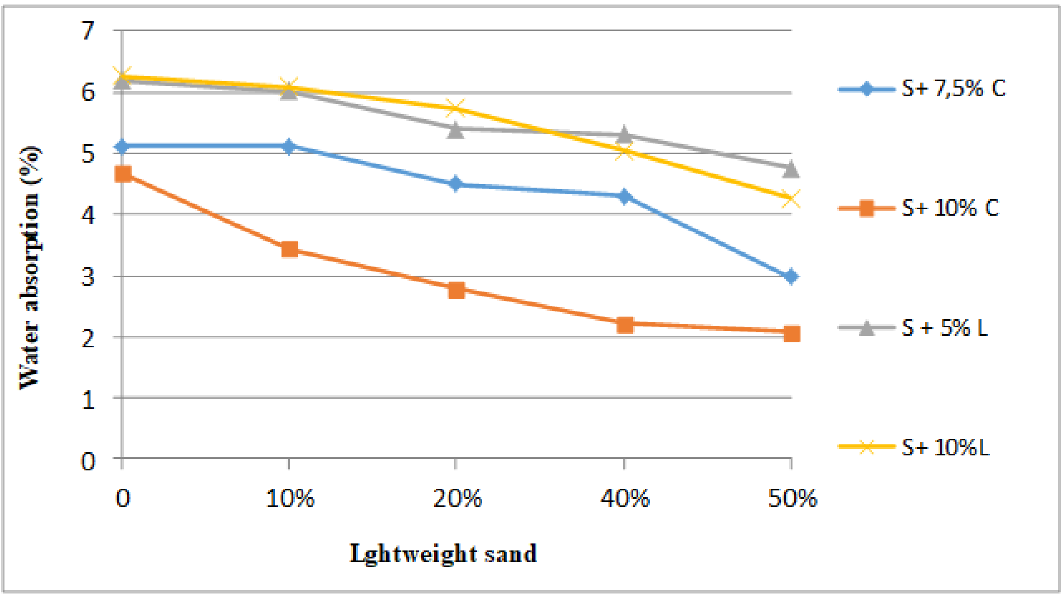

Figure 6. Absorption test for blocks based on cement, lime and lightweight sand

According to the results, a decrease in absorption is observed when the percentage of light sand increases. The stabilized blocks made with 40% and 50% light sand, stabilized with 10% cement, have a lower absorption compared to the stabilized earth blocks with 10% and 20% light sand, stabilized at 5% and 10% with lime, as well as at 7.5% with cement. Increasing the percentage of light sand seems to improve the resistance to water absorption of the stabilized blocks. Stabilizing the earth blocks by adding and increasing the dosage of light sand significantly reduces the water absorption rate.

Wetting-Drying Test

The wetting/drying durability test was also conducted in the laboratory. According to ASTM D559-57 standard, the procedure consists of immersing the blocks in water for 5 hours and then putting them in an oven at a temperature of 71°C for 42 hours. Then, the samples were brushed to remove the soil fragment affected by wetting and drying cycle. This procedure is repeated six times. Obtained results are represents in figures 7 and 8.

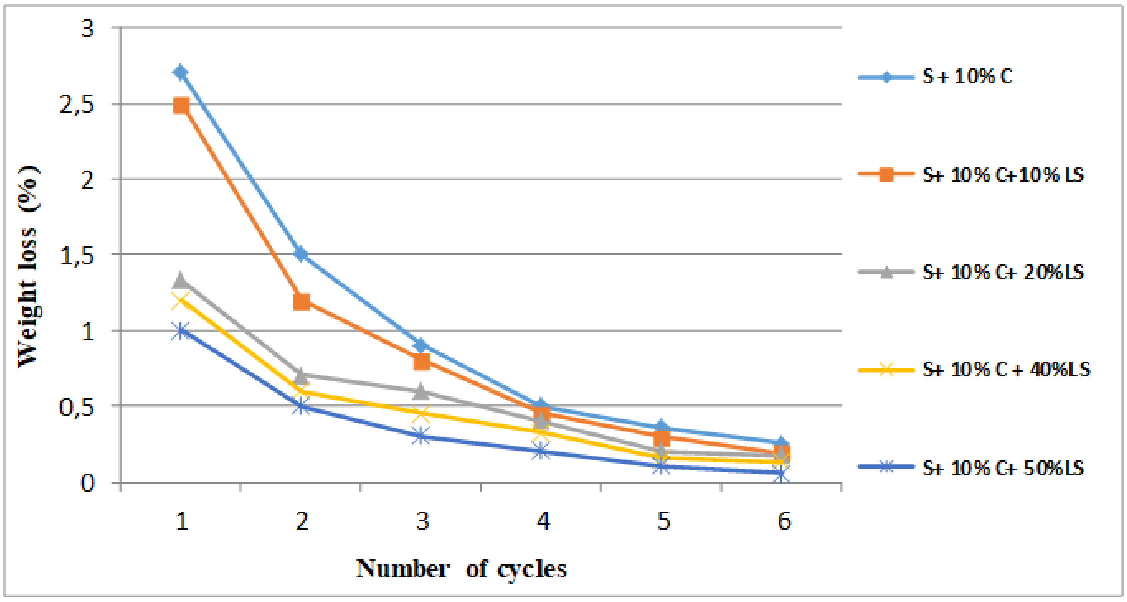

Figure 7. Wetting-drying test after 6 cycles for blocks based on lightweight sand and 10% cement

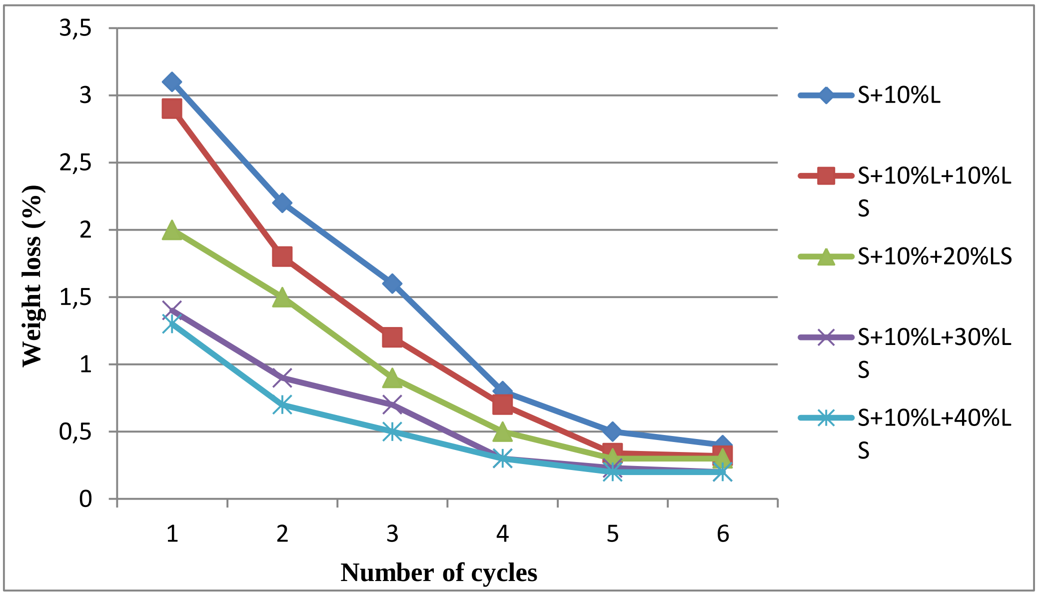

Figure 8. Wetting-drying test after 6 cycles for blocks based on lightweight sand and 10% lime

According to the results, a correlation is observed between the percentage of light sand used in the manufacture of stabilized blocks and the weight loss manifested. More precisely, an increase in the percentage of light sand seems to lead to a decrease in weight loss. This suggests that the use of a higher percentage of lightweight sand in combination with a fixed amount of lime can lead to a better stability of the earth blocks and therefore to a decrease in weight loss.

Compressive Strength Test

The compression test was carried out according to the XP P13-901 standard. Three samples were tested for each variant in order to evaluate the compressive strength of the stabilized earth block with a regular load speed of approximately 1.5 mm/min. An increase in the dosage of lightweight sand for blocks stabilized with cement or those with lime appears to lead percentage of lightweight sand, to an increase in the mechanical strength of the blocks. This can be explaining by the properties of lightweight sand, such as its particle size and density. The larger particles of lightweight sand and its hardness can help to strengthen the structure of the blocks and increase their mechanical strength.

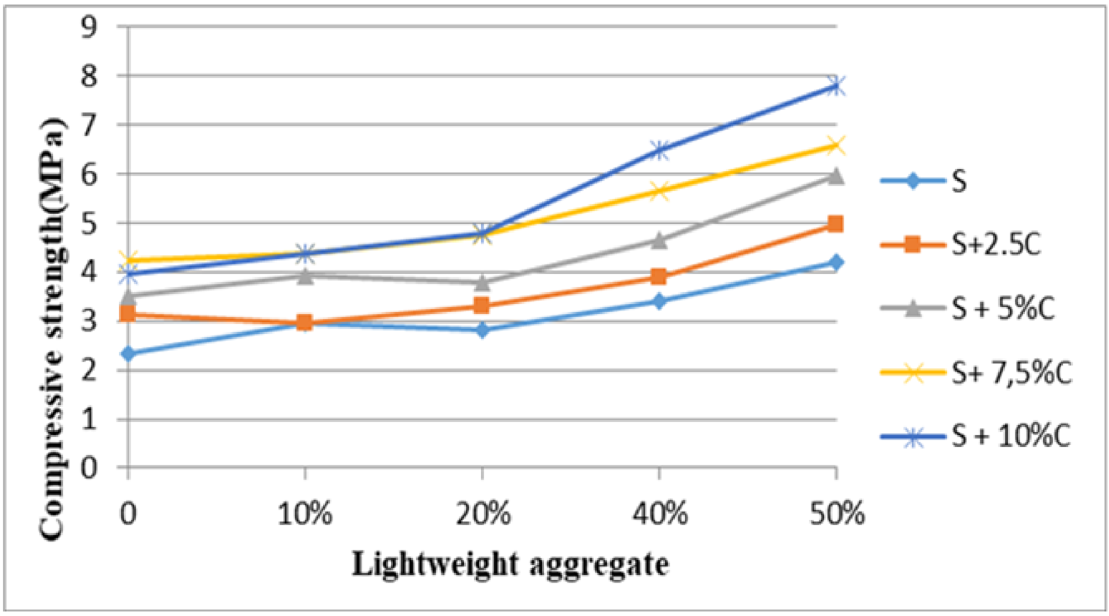

Figure 9. Compressive strength of stabilized blocks based on lightweight sand and cement

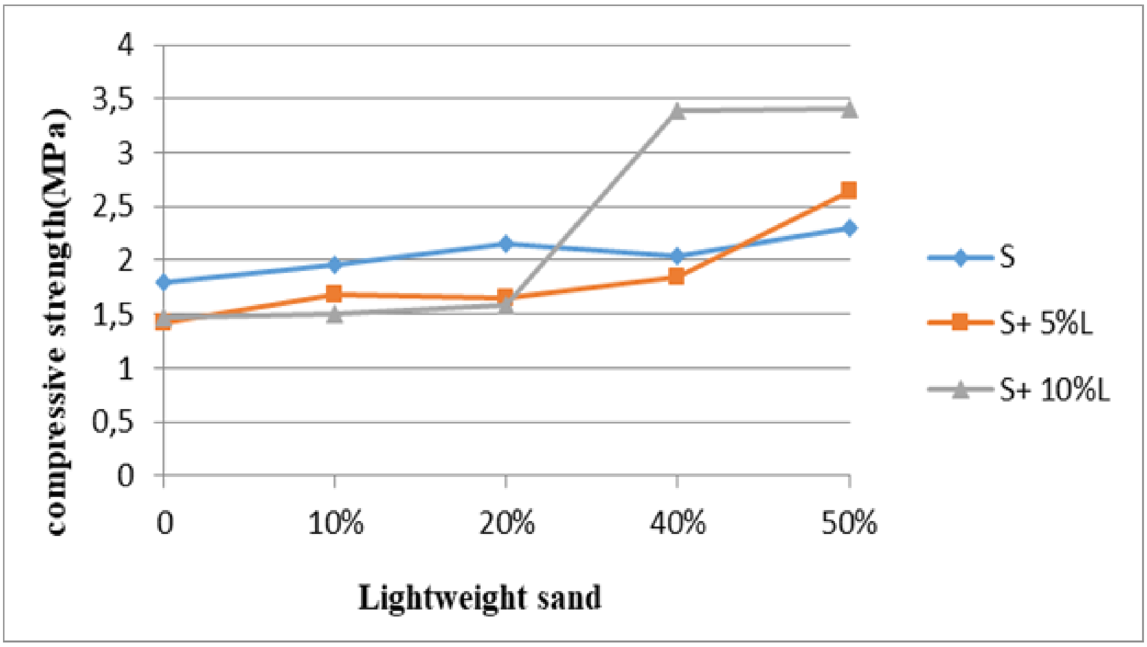

Figure 10. Compressive strength of stabilized blocks based on lightweight sand and lime

Bulk Density Test

The use of lightweight sand in the manufacture of stabilized earth blocks (SEB) can result a decrease in the density of the blocks. This reduction depends on the percentage of lightweight sand used in the mix. Using 50%, lightweight sand in the manufacture of blocks can result in a weight reduction of 5.05% compared to the blocks made with sediment only. A lower density means a lower weight per unit volume, which makes them easier to handle and transport to the construction site. The results of bulk density test are indicating in figure 11.

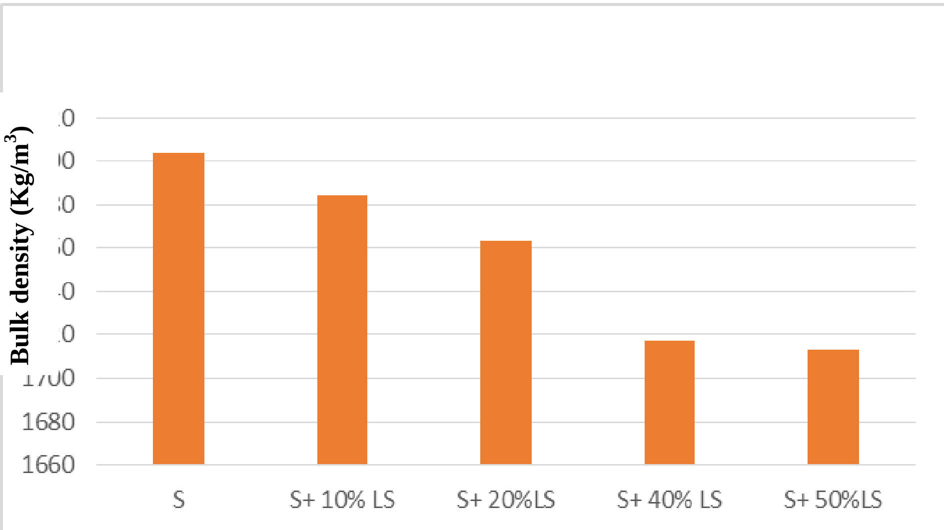

Figure 11. Bulk density of stabilized blocks with lightweight sand

Thermal Conductivity

Thermal conductivity is measured according to standard NF EN 993-15 using a CT-Meter, which operates on the hot wire principle. The results show that thermal conductivity decreases with increasing percentage of light sand. Lightweight sand is characterized by a porous structure, which can reduce the transmission of heat through the material. The pores present in lightweight sand can trap air or other gases, which are poor conductors of heat. Thus, the more lightweight sand there is in the material, the more pores there are and the less efficiently heat can propagate through the material.

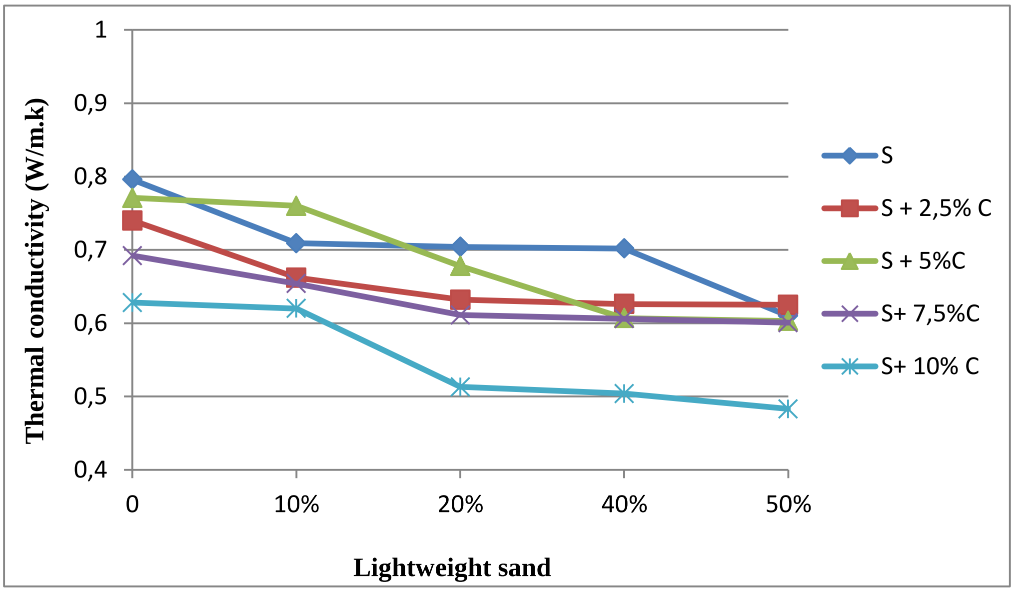

Figure 12. Results of thermal conductivity tests of blocks based on cement

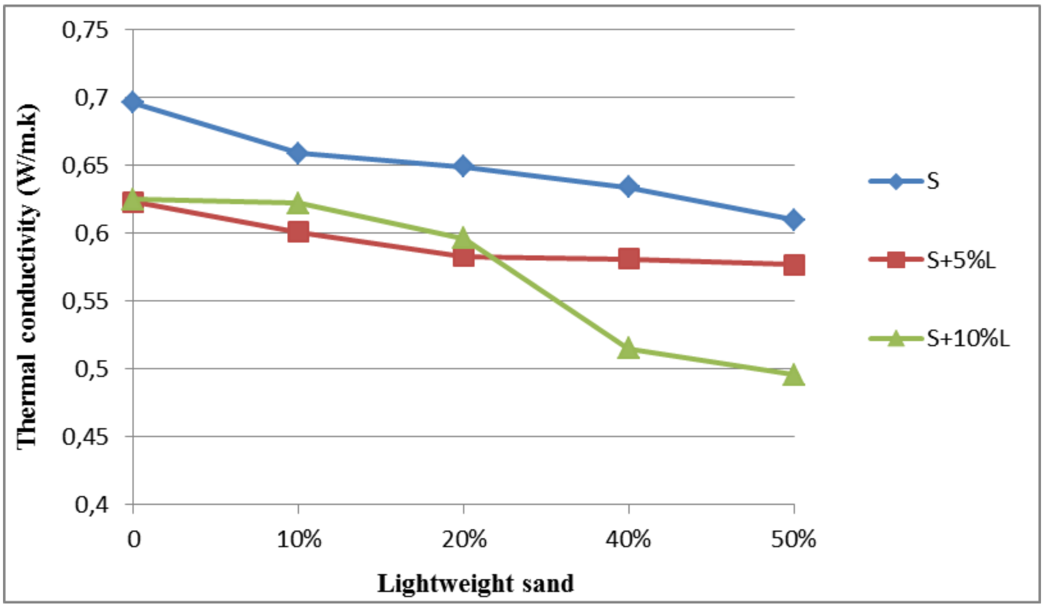

Figure 13. Results of thermal conductivity tests of stabilized blocks based on lime

Conclusion

From all the obtained results, it can be conclude:

- The use of lightweight sand in the composition of the blocks improves the shrinkage properties higher percentage of lightweight sand in combination with a fixed amount of lime or cement can lead to a better stability of the blocks and a decrease in weight loss. This is confirmed by the results obtained, the stabilized earth blocks made by sediment with 40% and 50% light sand stabilized by cement (7.5% and 10%) and stabilized by lime (5% and 10%) presenting less shrinkage.
- The blocks made with a higher percentage of light sand present a lower water absorption. This results in a decrease in weight loss and an increase in their durability. The samples made with 40% and 50% lightweight sand stabilized with 10% cement and 10% lime show good stability.

- Improved thermal insulation: The porous characteristics of lightweight sand allow reducing the heat transmission through the blocks. By increasing the percentage of lightweight sand, the thermal insulation of the blocks can be optimized. The tested stabilized blocks exhibit good thermal insulation with a thermal conductivity of 0.643 W/m.k for stabilized blocks with 10% cement 50% light sand and 0.496 W/m.k for blocks stabilized with 10% lime and 50% light sand.

The use of dam sediments, lightweight aggregates and stabilizers such as lime or cement in the manufacture of stabilized earth blocks allows obtaining blocks with good shrinkage properties, low water absorption, better stability, improved thermal insulation and increased mechanical strength. This offers interesting prospects for sustainable and ecological construction.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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