Valorization of the Recovered Lime in Cement-Typha Concretes: Thermal and Mechanical Behavior

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Abstract. In a context of sustainable development and reduction of energy consumption in the building sector, plant-based concretes are increasingly developed. These materials offer excellent thermal properties, with low mechanical properties, but sufficient for use as a filling material. Moreover, Typha is an invasive plant with harmful consequences on our environment. This work investigates the valorization of recycled lime in Typha-cement thermal insulation materials. The mechanical and thermal properties of these composites are studied according to lime percentage used in substitution of cement. The results show that the compressive strength of the concrete ranges from 1.34 to 2.30 MPa. Thermal results range from 0.078 to 0.192 $W.m^{-1}K^{-1}$ for thermal conductivity and 385.68 to 505.18 $J.m^{-2}.\ K^{-1}.\ s^{-\frac{1}{2}}$ for thermal effusivity.

Keywords: Typha · Cement · Recovered lime · Compressive strength · Thermal characterization

1 Introduction

In recent years, the world is confronting an increasing demand for energy. This high demand impacts not only the energy supplies due to the depletion of natural resources but also the environment, in particular global warming and climate change. The contribution of building sector represents 20 to 40% of energy consumption in developed countries [1] against 25 to 30% of total electricity consumption and 49% of carbon dioxide emissions in West Africa [2]. According to the 2019 report of the UEMOA Energy Information System, the Senegalese residential sector accounts for 62% of total final electricity consumption in the UEMOA space [3]. This high energy consumption in the residential sector is due in part to a failure of thermal insulation in buildings.

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Depending on the geographical location and the season, occupants often have to resort to air conditioning or heating to have thermal comfort inside the building. However, a large part of the heating or cooling demand is caused by transmission losses through the building envelope [4]. Energy efficiency of buildings is therefore an important challenge for the reduction of energy consumption in the building sector. In this context, several researchers have developed thermal insulation materials-based plant fibers. Natural fibers are light, renewable, insulating, less expensive than glass fibers and Bio-based materials allow carbon storage during their growing [5]. In addition, bio-based materials respect environmental criteria during their life expectancy, unlike conventional insulation materials like polystyrene, polyurethane and glass wool [6]. However, the development of vegetal concretes is slowed down by their weak mechanical performances resulting from the high compressibility of the vegetal granulate [7]. Moreover, plant fibers contain sugars that can inhibit cement hydration and negatively affect the mechanical performance of composites. Unlike conventional concretes with compressive strengths of about 30 MPa, plant-based concretes have very low compressive strengths that depend on the nature of the particles and the composition of the vegetable concretes [7]. Many studies have been carried out to understand the interactions between plant fibers and the cement matrix. Delannoy et al. [8] studied the impact of hemp extracts on hydration of Portland Cement. Results show that the adsorption of monosaccharide (cellulose and hemicellulose) on anhydrous cement grains delays the setting by physisorption. In the presence of calcium, non-reducing sugars (sucrose) form complexes and bind to hydrates and prevent their growth [8]. Bekir Çomak et al. [9] studied the effect of hemp fibers on the physical and mechanical properties of cement-based mortars. Sedan et al. [10] studied the influence of chemical interactions between cement and hemp fibers on the mechanical behavior of hemp-cement composites. Govin et al. [11] studied the relative effectiveness of polysaccharides and their influence on cement hydration. The retarding effect of polysaccharides depends on the cement composition. To improve the adhesion between the plant fibers and the cement matrix, several methods have been used by researchers, in particular treatment of fibers or addition of additives to the matrix. Weyenberg et al. [12] used an alkaline treatment to improve the mechanical properties of the flax-epoxy composite. Terpáková et al. [13] studied the chemical modification of hemp shives after treatment with sodium hydroxide, calcium hydroxide and ethylene-diamine-tetra acetic acid. Sawpan et al. [14] studied the effect of hemp fiber treatments on the interfacial shear strength of hemp fiber-reinforced unsaturated polylactide and polyester composites. A lot of research has been conducted on the valorization of typha in construction materials. In 2016, Diaw et al. [15] studied the valorization of typha by its incorporation in building materials. In 2017 Dieye et al. [2], studied the thermomechanical properties of a typha-based building material. In 2018, Niang et al. [16] studied the thermal and hygroscopic performance of various typha-clay composites. In 2021, Diaw et al. [5] studied the characterization of cement-reinforced Typha-clay composites. More and more wastes are valorized in building materials. Bal et al. [17] used millet waste in laterite-based building materials to improve their insulation properties. Bouhamou et al. [18] have valorized extracted silt in the development of concrete and construction materials. The objective of this study is to valorize lime recovered in insulation materials cement-typha. The second part of this document deals with the experimental program, the raw materials used, the preparation of the samples as well as the different characterizations are described. The third part is devoted to the results and discussion and finally a conclusion and finally, a conclusion and some perspectives put end this document.

2 Experimental Program

2.1 Raw Materials

The plant particles used in this study are extracted from typha plant. Typha Australis is a monocotyledonous plant belonging to the Typhaceae family [19]. The typha used in this study was harvested from the Senegal River. It was then sun-dried and crushed to obtain typha fibres (tf). Figure 1 and Fig. 2 show the Typha fibers and their particle size analysis, respectively. Fibers are very light with an apparent (or bulk) density of 24 kg/m^3.

Fig. 1. Typha fiber

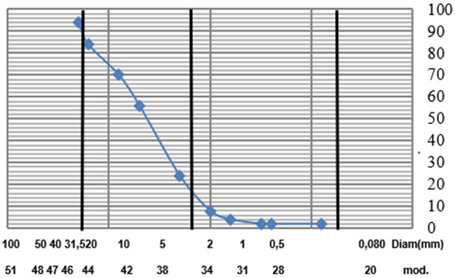

Fig. 2. Granulometric analysis of typha particles

The matrix used is composed of cement and recycled lime. The cement (c) is a Portland cement type CEM II/B 32, R with a density of 1.34 g/cm^3. The characteristics of clinker and cement are presented in Table 1. The hydrated lime used in this study comes from the Keur Momar Sarr drinking water treatment plant, 300 km from Dakar, Senegal. The lime was used to improve water quality, especially to soften the water and remove arsenic. After use, the residue was rejected into nature. In this work, the residue was collected and dried in an oven at 50 °C. The product was then crushed and sieved. The powder obtained was conditioned in bags to protect it from humidity and air. The density of lime is 0.58 g/cm^3.

Table 1. Physical and chemical properties of cement

Chemical characteristics of clinker		Physico-chemical characteristics of cement	
C_3A (%)	6.70	Blaine	4330
C_4AF (%)	10.89	beginning of setting time (min)	261
C_3S (%)	60.54	Hot stability (mm)	1.70
C_2S (%)	14.25	S_3O content (%)	2.33
Lime standard	0.982	Loss on ignition (%)	12.0
Silicic modulus	2.48	Insoluble residue (%)	2.00
Aluminum-Ferric Index	1.39	Chlorides content (%)	0.01
		Adding limestone (%)	28.2
		Compressive strength (MPa) 2 days	12.6
		Compressive strength (MPa) – 7 days	24.1
		Compressive strength (MPa) – 28 days	37.8

2.2 Samples Preparation

To prepare typha-cement composites, cement and water were mixed in a pan mixer for 2 min before typha fibers was added. The mixing then continued for another 3 min. The mix proportion of typha-cement composites (TCC) was set at c/tf of 250 kg/1 m^3. This formulation corresponds to the smallest amount of cement that can be mixed with 1 m3 of typha fibres to obtain a strong concrete. Below 250 kg of cement, the formulated concretes have cracked. A water/cement (w/c) ratio of 0.6 was used for TCC and the amount of water was adjusted for TCLC to ensure workability of the concretes. Table 2 presents the mix proportion of TCC and TCLC. The mixture was placed in different cylindrical and parallelepipedic molds for the compressive strength test and thermal test. To improve the mechanical performance of TCC, the cement was substituted by lime recycle at 10, 20 and 30% by weight, respectively. Block specimens with 10, 20 and 30% of lime were named 10TCLC, 20TCLC and 30TCLC, respectively.

Table 2. Mix proportion of TCC and TCLC.

Sample	Typha (g)	Cement (g)	Lime (g)	Water (g)
TCC	700	7291.7	0	4447.9
10TCLC	700	6562.5	729.2	4732.3
20TCLC	700	5833.3	1458.3	5016.7
30TCLC	700	5104.2	2187.5	5301.0

2.3 Mechanical Test Methods

To carry out the mechanical tests, cylindrical specimens of 110 mm diameter and 220 mm height were made. They were then conserved in their mold with one side exposed to the air during 48 h. They were removed from the molds and placed in the open air in the laboratory. Simple compression tests were carried out at 28 days using a hydraulic press with a load of 50 kN. The testing machine can be seen in Fig. 3.

Fig. 3. Compression testing machine

2.4 Thermal Characterization

Thermal characterization of concretes was carried out by hot plate method using parallelepipedic samples of dimensions 10 × 10 × 2 cm^3. This method is used in an asymmetrical configuration because it is almost impossible to find two identical materials in their form and composition in construction [2, 20]. The heating element on which a thermocouple is fixed in its center is placed under the sample to be characterized. A 5 cm thick polystyrene block is placed under the heating element and another on top of the sample. The whole is placed between two 4 cm thick aluminum blocks. Thermal characterization of samples is represented in Fig. 4. The principle of this method consists of to apply a constant thermal flux to the heating element and to record the evolution of the temperature Ts (t) at the center of the heated face of the sample. By overlaying the experimental and theoretical temperature, thermal conductivity and diffusivity of the sample can be determined. The theoretical model of the temperature at the center of the heated face of the sample is presented in [20].

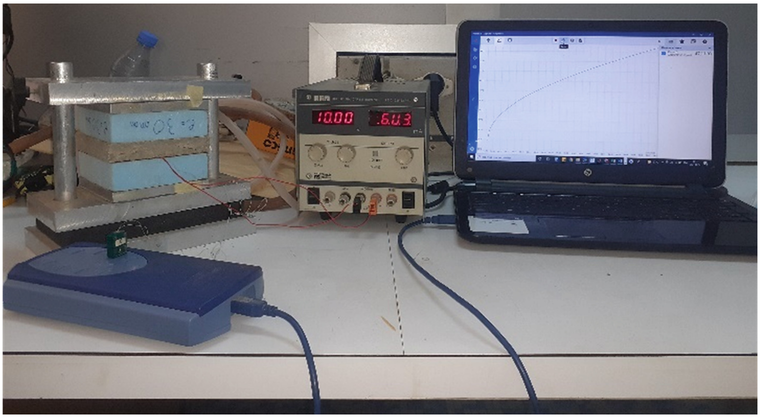

Fig. 4. Thermal characterization of samples.

3 Results

3.1 Bulk Density of Samples

The evolution of samples density as a function of lime percentage is represented in Fig. 5. The results show that increasing lime amount leads to decrease the bulk density. Indeed, cement is denser than lime. The substitution of cement by lime leads to a lightness of the material. Indeed, the density of lime is lower than that of cement. Consequently, a substitution of cement by lime leads to a decrease in the density of concrete.

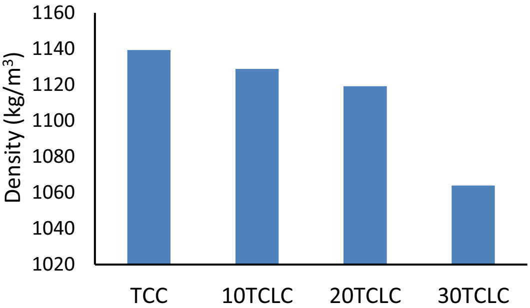

Fig. 5. Bulk density of TCC and TCLC

3.2 Mechanical Results

The results of compressive strength according to lime percentage are shown in Fig. 6.

The compressive strength of the composites ranges from 1.342 and 2.297 MPa.

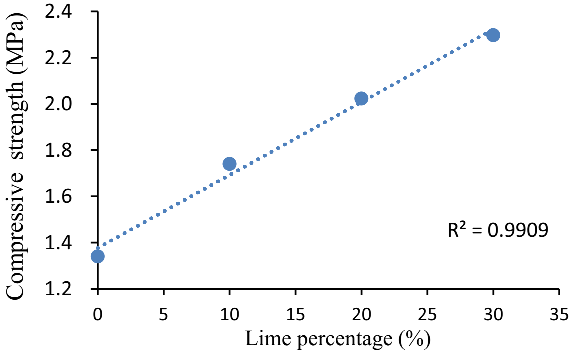

Fig. 6. Compressive strength of TCC and TCLC

The results show that compressive strength increases with increasing lime percentage. These results are slightly higher to compressive strength of Typha-clay concretes which range from 0.279 to 0.796 MPa [2] and cement-reinforced Typha-clay composites which range from 0.14 to 0.71 MPa [5]. Figure 7 shows the evolution of applied load according to lime percentage during the compression test. We can note that applied load increases progressively until it reaches a maximum and then decreases. As can be seen, the increase in the amount of lime leads to an increase in the applied load due to the fact that the material becomes more resistant (but less ductile). Indeed, the loss of performance of typha-based cementitious concretes would be due to the decomposition of the cellulose and hemicellulose of which they are composed in the alkaline environment of the cementitious matrices. In addition, the pectin contained in typha fibres fixes calcium Ca^{2+} and hydroxide OH^- ions on the surface of the fibres. A deficit of calcium and hydroxide ions is then observed in the interstitial phase, leading to an inhibition of calcium silicate hydrates (CSH), the main product of the hydration of a hydraulic binder, and thus a delay in the setting of the cement. The introduction of lime has improved the compressive strength of concrete. The introduction of lime leads to a decrease in the alkalinity and $Ca(OH)_2$ content of the cementitious matrix, responsible for the mineralization and fragility of the fibres.

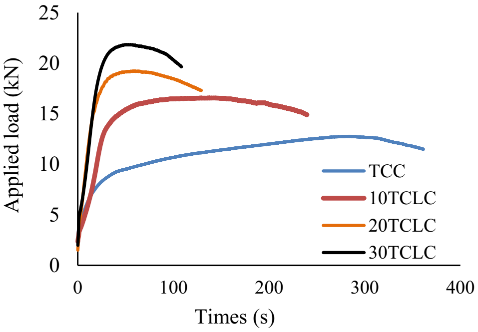

Fig. 7. Applied load according lime percentage

3.3 Thermal Results

The evolution of thermal conductivity and thermal effusivity of the samples are represented in Fig. 8 and Fig. 9, respectively. An increase of thermal conductivity and thermal effusivity is observed as a function of the recovered lime content. These values range from 0.078 to 0.192 $W.m^{-1}. K^{-1}$ for thermal conductivity and 385.68 to 505.18 $J.m^{-2}. K^{-1}. s^{-\frac{1}{2}}$ for thermal effusivity.

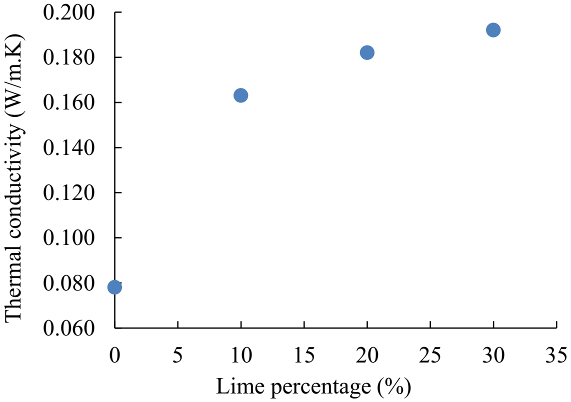

Fig. 8. Thermal conductivity of TCC and TCLC

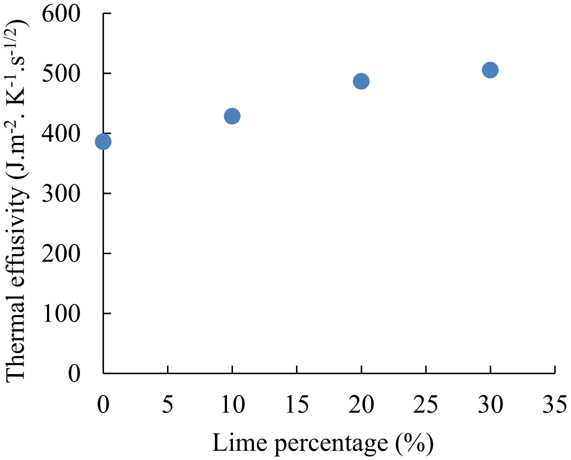

Fig. 9. Thermal effusivity of TCC and TCLC

Indeed, the thermal conductivity of lime paste (0.7 $W.m^{-1}. K^{-1}$) [21] is higher than that of cement (0.53 $W.m^{-1}. K^{-1}$) [5]. This explains the increase in thermal conductivity of concrete when the quantity of lime increases. According to Fatim et al. [22] addition of lime deteriorates the thermal inertia of the material.

4 Conclusion

This work consisted in valorizing lime mud recovered in building materials. The mechanical and thermal performances of the materials were evaluated according to the quantity of lime added. The results show an improvement in the compressive strength of the materials and a slight increase in the thermophysical properties of the materials. However. A microstructural study is needed to understand more closely the effect of lime on the interfacial bonding between fiber and cement matrix. This study shows that the valorization of waste materials in construction materials can improve its mechanical performance while maintaining its insulating properties.

References

1. Pérez-Lombard, L., Ortiz, J., Pout, C.: A review on buildings energy consumption information. Energy Build. **40**(3), 394–398 (2008). https://doi.org/10.1016/j.enbuild.2007.03.007
2. Dieye, Y., Sambou, V., Faye, M., Thiam, A., Adj, M., Azilinon, D.: Thermo-mechanical characterization of a building material based on Typha Australis. J. Build. Eng. **9**, 142–146 (2017). https://doi.org/10.1016/j.jobe.2016.12.007
3. Système d'Information énergétique des États membres de l'UEMOA. RAPPORT 2019 Chiffres clés sur l'énergie au Sénégal et dans l'espace UEMOA (2019)
4. Berggren, B., Wall, M.: Calculation of thermal bridges in (Nordic) building envelopes - risk of performance failure due to inconsistent use of methodology. Energy Build. **65**, 331–339 (2013). https://doi.org/10.1016/j.enbuild.2013.06.021
5. Diaw, I., Faye, M., Bodian, S., Sambou, V.: Characterization of cement-reinforced Typha-clay composites. J. Sci. Eng. Res. **8**(12), 123–128 (2021)
6. Osseni, S.O.G., Apovo, B.D., Ahouannou, C.: Caractérisation thermique des mortiers de ciment dopés en fibres de coco par la méthode du plan chaud asymétrique à une mesure de temperature. Afrique Sci. **12**(6), 119–129 (2016)
7. Akkaoui, A.: Bétons de granulats de bois : Étude expérimentale et théorique des propriétés thermo-hydro-mécaniques par des approches multi-échelles. Ph.D. thesis (2014)
8. Delannoy, G., et al.: Impact of hemp shiv extractives on hydration of Portland cement. Constr. Build. Mater. **244**, 118300 (2020). https://doi.org/10.1016/j.conbuildmat.2020.118300
9. Çomak, B., Bideci, A., Bideci, Ö.S.: Effects of hemp fibers on characteristics of cement based mortar. Constr. Build. Mater. **169**, 794–799 (2018). https://doi.org/10.1016/j.conbuildmat.2018.03.029
10. Sedan, D., Pagnoux, C., Smith, A., Chotard, T.: Mechanical properties of hemp fibre reinforced cement: influence of the fibre/matrix interaction. J. Eur. Ceramic Soc. **28**(1), 183–192 (2008). https://doi.org/10.1016/j.jeurceramsoc.2007.05.019
11. Peschard, A., Govin, A., Grosseau, P., Guilhot, B., Guyonnet, R.: Effect of polysaccharides on the hydration of cement paste at early ages. Cement Concr. Res. **34**(11), 2153–2158 (2004). https://doi.org/10.1016/j.cemconres.2004.04.001
12. Van de Weyenberg, I., Truong, T.C., Vangrimde, B., Verpoest, I.: Improving the properties of UD flax fibre reinforced composites by applying an alkaline fibre treatment. Compos. Part A: Appl. Sci. Manuf. **37**(9), 1368–1376 (2006). https://doi.org/10.1016/j.compositesa.2005.08.016
13. Terpáková, E., Kidalová, L., Eštoková, A., Čigášová, J., Števulová, N.: Chemical modification of hemp shives and their characterization. Procedia Eng. **42**, 931–941 (2012). https://doi.org/10.1016/j.proeng.2012.07.486

14. Sawpan, M.A., Pickering, K.L., Fernyhough, A.: Effect of fibre treatments on interfacial shear strength of hemp fibre reinforced polylactide and unsaturated polyester composites. Compos. Part A: Appl. Sci. Manuf. **42**(9), 1189–1196 (2011). https://doi.org/10.1016/j.compositesa.2011.05.003
15. Diaw, A.S., Sow, D., Ndiaye, M.B., Abdelakh, A.O., Wade, M., Gaye, S.: Valorization of Typha Australis by its integration in building construction materials. Int. J. Emerg. Technol. Adv. Eng. **6**(1), 34–37 (2016)
16. Niang, I., et al.: Hygrothermal performance of various Typha–clay composite. J. Build. Phys. **42**(3), 316–335 (2018). https://doi.org/10.1177/1744259118759677
17. Bal, H., Jannot, Y., Quenette, N., Chenu, A., Gaye, S.: Water content dependence of the porosity, density and thermal capacity of laterite based bricks with millet waste additive. Constr. Build. Mater. **31**, 144–150 (2012). https://doi.org/10.1016/j.conbuildmat.2011.12.063
18. Belas, N., Belaribi, O., Mebrouki, A., Bouhamou, N.: Valorisation des sédiments de dragage dans les bétons. Séminaire International, Innovation et Valorisation en génie Civil et Matériaux de construction, Rabat (Maroc), vol. 23, p. 25 (2011)
19. Ba, L., Abbassi, I.E., Kane, C.S.E., Darcherif, A.M., Ndongo, M.: The challenges of local and bio-sourced materials on thermal performance: review, classification and opportunity. Int. J. Eng. Res. Africa **47**, 85–101 (2020). https://doi.org/10.4028/www.scientific.net/JERA.47.85
20. Diaw, A.S., Bal, H.M., Diallo, O., Ndiaye, M.B., Wade, M., Gaye, S.: Thermophysical characterization of Typha's concrete for its integration into construction. J. Build. Constr. Plann. Res. **9**(1), 56–65 (2021). https://doi.org/10.4236/jbcpr.2021.91005
21. Brzyski, P., Lagód, G.: Physical and mechanical properties of composites based on hemp shives and lime. In: E3S Web of Conferences, vol. 49, pp. 1–8 (2018). https://doi.org/10.1051/e3sconf/20184900010
22. Zoma, F., Yonli, F.H., Malbila, E., Toguyeni, D.Y.K., Hassel, I.B.: Adding hydrated lime in a material made of clayey soil and fibres: formulation and effects on thermo-mechanical properties. J. Miner. Mater. Charact. Eng. **8**(3), 149–161 (2020). https://doi.org/10.4236/jmmce.2020.83010