Development of eco-materials for noise barriers

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RESUME Noise barriers are the most effective and widespread solution for reducing traffic noise. However, their manufacture relies heavily on the use of cement, which has a significant environmental impact. In this context, the development of an innovative material that combines earth stabilization and foaming with the incorporation of hemp particles presents a promising alternative. In this study, earth stabilization is achieved using LC^3 (Limestone Calcined Clay Cement). The foaming and the incorporation of hemp particles contribute to the creation of a porous material with enhanced acoustic insulation properties. Pastes with various compositions were produced to analyze the compatibility of earth and LC^3. The results showed compressive strengths at 90 days of hydration evolving between 0.5 MPa and 3.2 MPa adjusting the LC^3-content. Multiple foam formulations were developed by varying the proportions of hemp, water, and surfactant. These samples were then characterized in the laboratory to assess the link between the formulation and the porosity.

Mots-clefs noise barriers, earth, bio-based material, LC^3, porous materials

I. INTRODUCTION AND STATE OF THE ART

Noise pollution is a major environmental concern, with road traffic being one of the main sources and contributors to health issues (European Environment Agency, 2021). Noise barriers are a common mitigation strategy, typically built between roads and sensitive areas using various materials (Ekici *et al.*, 2003; Laxmi *et al.*, 2021). In France, approximately 100,000 m² of new noise barriers are installed each year (Cerema, 2022). Therefore, this study aims to develop and assess a new eco-friendly material for noise barriers: a foam composite made of earth stabilized with LC^3 (Limestone Calcined Clay Cement) and hemp shiv particles. Clay soil was chosen for its abundance, though it requires stabilization to improve strength and durability due to moisture sensitivity and shrink-swell behavior (Ijaz *et al.*, 2022; Khemissa *et al.*, 2014). LC^3, emitting 20–23% less CO_2 than OPC, is used as a stabilizer (Scrivener *et al.*, 2017). Hemp shiv, with its lightweight and porous structure, enhances acoustic and thermal performance while lowering carbon impact—up to 1,800 kg of CO_2 can be sequestered per ton produced (Protchenko, 2019).

II. MATERIALS AND METHODS

Two types of earth materials were used: FAC (*fines argilo-calcaires* – calcareous clay fines, from *Carrières du Boulonnais* (Leulinghen-Bernes, France)) and FA (*fines argileuses* – clay fines, from *Carrière des Housseaux* (Montreuil-Poulay, France)), both by-products of aggregate washing processes. FAC is mainly composed of calcite (76%), with small proportions of muscovite/illite (9%), quartz (8%), and kaolinite (6%), while FA contains mostly quartz (36%), kaolinite (34%), and muscovite/illite (30%). Their grain size distributions are similar (D_{mean} = 10 µm).

The binder used was LC^3-50 (50% cement), with a typical composition of CaO (46%), SiO_2 (27%), Al_2O_3 (9%), and a fire loss at 950°C equal to 7% (Prud'homme *et al.*, 2024). Some formulations also included 8 mm hemp shiv particles (Isofin, Cavac) as lightweight particles with intermediate pore size. Hostapur OSB (Clariant) was used as the foaming agent due to its high efficiency at low concentration and easy solubility (Mortada, 2021).

Paste samples made of earth, LC^3, and water were first prepared to assess compatibility between binder and earth materials. Five formulations with similar consistency (adjusted via water content using a penetrometer; see Table 1) were mixed using a Kenwood mixer with a blade: earth and water for 2 min at low speed, then LC^3 added and mixed for 2 more minutes.

Cylindrical specimens (2 cm × 4 cm) were cast and moist-cured. Axial compression tests were performed at 72 h, 7, 28, and 90 days.

Next, foam samples were prepared with varying hemp-to-binder (h/b) ratios (0–12 wt%) and water-to-binder (w/b) ratios. All used 12.5 wt% LC^3 + 87.5 wt% FA (or FAC) as binder. A fixed foaming agent-to-water ratio of 0.09 wt% was used. The w/b ratio was adjusted to maintain iso-rheology of the foams reach pre-foaming shear stresses of 0.31 ±0.02 kPa evaluated using a penetration test.

Mixing was done with a KitchenAid mixer: water and FA for 2 min, then LC^3 for 2 min, hemp for 1 min. Finally, foaming agent was added and the mix whipped until a target bulk density of 820–920 kg/m³ was reached.

TABLE 1. Paste formulations

Paste	**LC^3-100**	**FAC-25**	**FAC-12,5**	**FA-25**	**FA-12,5**
Binder composition	100% LC^3	25% LC^3, 75% FAC	12.5% LC^3, 87.5% FAC	25% LC^3, 75% FA	12.5% LC^3, 87.5% FA
w/b mass ratio	0,45	0,55	0,55	0,87	0,95

IV. PRELIMINARY RESULTS, DISCUSSION AND OUTLOOK

Figure 2 shows the evolution of compressive strength for earth–LC^3 pastes. The 100% LC^3 samples achieved the highest strength, approximately 30 MPa at 90 days, though with variability between 28 and 90 days. For FAC–LC^3 pastes, strength reached 3.2 MPa (25% LC^3) and 1.4 MPa (12.5% LC^3) at 90 days. As expected, higher LC^3 content improved strength. FA–LC^3 pastes performed worse, with 90-day strengths of 1.5 MPa (25% LC^3) and 0.5 MPa (12.5% LC^3), likely due to higher water demand, which negatively impacted strength.

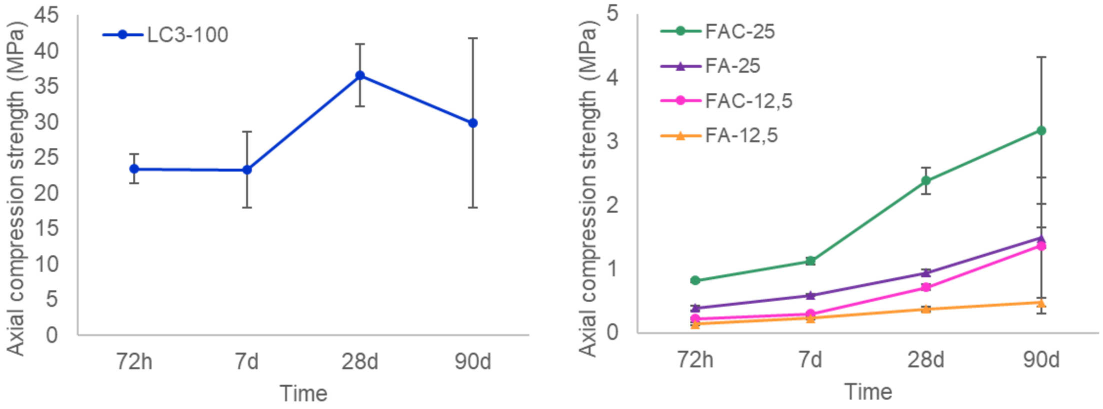

FIGURE 2. Evolution of earth-LC³ pastes axial compressive strength with curing time

Figure 3 shows the correlation between porosities and bulk density for FA-LC³ dry foam samples. Four types of porosities are distinguished: water porosity, from the evaporation of the free water present in the mineral matrix; hemp porosity, due to voids in the hemp shiv particles; air porosity, due to the air bubbles generated by the foaming process; and total porosity, the sum of the three porosities. The tested formulations lead to a wide range of accessible bulk densities, from 467 to 637 kg/m³.

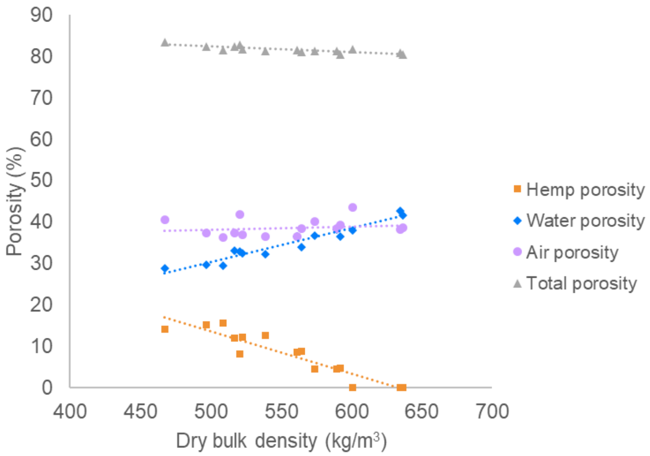

FIGURE 3. Relationship between bulk density and porosities of FA–LC³ foam samples

Introducing hemp in formulation leads to a decrease in the foam bulk density and, as expected, increases the hemp porosity. Conversely, the water porosity decreases. The introduction of hemp leads to a more compact mineral matrix. Since all samples were foamed to reach the same target density, the air porosity shows little variation. The pore structures (size of pores, connectivity) linked to the water porosity (pore between mineral particles), the air porosity (bubbles) and the hemp porosity present complementary acoustical interests affecting the sound absorption properties. Next steps include acoustic and mechanical testing of the foams to explore how porosities affect performance. All the results obtained should make it possible to create a design tool to identify the optimal formulation that will satisfy a set of acoustical specifications.

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