Investigation of mechanical behavior of flax and hemp concrete under compression using acoustic emission

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RESUME Bio-based materials are undergoing strong development nowadays in order to reduce environmental impact of the construction field. Nevertheless, there is a lack of knowledge relating to their mechanical behavior, and more particularly, their cracking and damage. Therefore, the objective of this research project is to analyze and monitor the damage evolution in hemp and flax concrete using the acoustic emission (AE) method. Hemp and flax shives were used to manufacture concrete with natural prompt cement (NPC). Flax concrete shows a delay in crack propagation in comparison to hemp concrete. These results are encouraging to study different types of bio-based concrete (in aggregate and binders).

Mots-clefs hemp, flax, concrete, damage, acoustic emission

I. INTRODUCTION

Hemp concrete and flax concrete are among the eco-materials that have many advantages as moisture regulator as well as thermal and sound insulator. In addition, raw materials are abundant in France. The area occupied by hemp agriculture is about 16400 hectares (Interchanvre, 2017). Normandy is the world's leading flax-producing region with an area of 73,000 hectares in 2019 (Fougy, 2020). Currently, the demand for these materials is growing despite the lack of knowledge about their mechanical behavior, and more specifically, their cracking and damage. Therefore, the objective of this research project is to analyze the damage of hemp concrete and flax concrete using the AE method in order to better understand the behavior of these emerging materials in the construction field. The AE technique consists in visualizing the acoustic waves generated by the microcracking during the mechanical test. AE waves propagate within the material and are detected by piezoelectric sensors placed at the surface that transform them into electrical signal which is then amplified and digitalized with an acquisition system. This method allows the detection, localization, and identification of damage mechanisms within the material under external stresses. This technique has already been used to characterize the damage evolution in raw earth-based materials (Kouta et al., 2021) but remains to be developed for bio-based materials with more or less porous surfaces.

II. MATERIALS AND METHODS

A. Hemp and flax shives

In this study, two types of bio-based aggregates are considered: hemp and flax shives. The used hemp shive is provided from Biofibat. Flax shive was supplied by the Agylin cooperative. They are mainly used for the manufacture of wooden boards and in very small proportion for horticulture. Note that, the flax sample also contains some fibers and seed residues. The bulk densities, thermal conductivity (obtained by the hot wire method) and water absorption at 24h of hemp and flax shives are presented in Table 1.

TABLE 1. Hemp and Flax shives properties

Shive	Bulk density (kg/m3)	Thermal conductivity (W/(m.K))	Water absorption at 24h (%)
Hemp	110.0 ± 4.4	0.061 ± 0.001	344 ± 9
Flax	99.9± 2.6	0.048 ± 0.001	340 ± 1

The grain size distribution of the two shives (Figure 1) has been characterized by image analysis according to the recommendations of RILEM TC 236-BBM (Amziane et al., 2017). The shives are distinguished by their minor axis which is weaker for flax shive, which induces a slightly lower circularity values for flax shive.

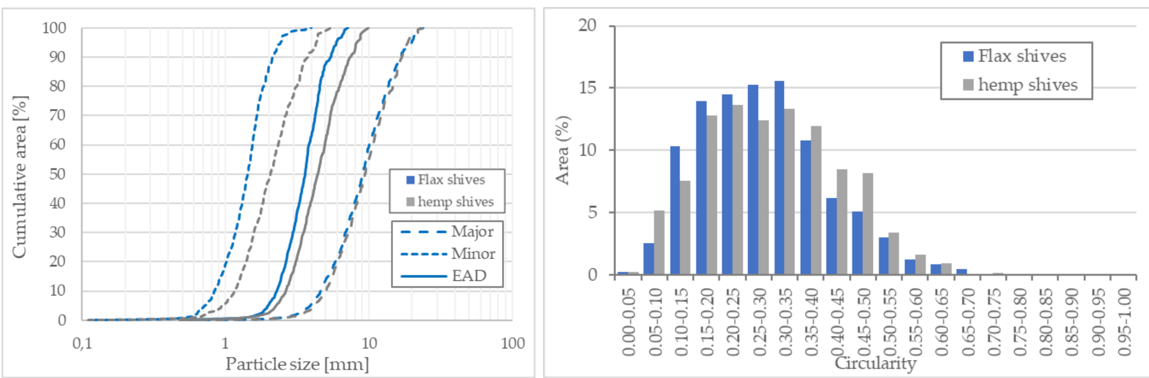

FIGURE 1. Particle size distribution and circularity of flax and hemp shives.

B. Hemp and Flax Concrete

The bio-based concretes studied in this article are composed of hemp and flax shives mixed to a natural prompt cement (NPC) with a bulk density of 2980 kg/m³. The use of NPC as a binder in vegetable-based concretes helps to limit the development of mold (Marceau et al., 2017). The water to binder ratio W/B was set to 1.5 and the binder to shive ratio B/S to 2. A citric acid setting retarder is used in the mixture at 0.1%wt. The specimens are manually compressed cylinders of ø11-22 cm. The hemp and flax concretes have bulk densities of 886 and 850 kg/m^3. The specimens are cured under ambient conditions (20°C, 22%HR) after demoulding at 3 days until the tests.

C. Acoustic emission technique

The used AE system consists of an eight channel AEWIN system with a general- purpose interface bus and a system for data storage analysis. A 3D localization algorithm has been used for the localization of AE events. Six R15a piezoelectric sensors were used with a frequency range between 50 and 200 kHz and a resonance frequency of 150 kHz. The detected signals were amplified with a 40 dB gain differential amplifier. The detection threshold is set at 30 dB to avoid the background noise. The location accuracy is estimated to be ±5 mm. The compressive test was performed with a 4mm/min speed.

III. RESULTS

Figure 2 shows the correlation between the amplitude, the load and the cumulated number of AE hits during the compression test. Linking the evolution of the cumulated number of AE hits with the load curve shows different phases. The AE activity is important for low loading level and begins from the beginning of test with high AE amplitude indicating a premature damage and the absence of the elastic phase as in ordinary concrete. The AE activity was more important for hemp concrete during the first phase indicating an important damage rate and a delay in crack evolution in flax concrete in comparison. The rate of the AE activity increases rapidly with high amplitudes during the second phase of flax concrete corresponding to the appearance of cracks while the rate decreases for hemp concrete indicating different crack propagation kinetics. After the peak, the AE activity decreases progressively indicating the stable propagation of the cracks. Note here, that the deformation of the bio-based concretes was very important after the peak and some cracked parts of the concrete were moved in the lateral direction out of the plane which reduces the reliability of AE measurements at the end of the test. The number of AE hits was more important in flax concrete which may be due to a higher matrix particle interconnections and cohesion at the interface between flax shives and the matrix as higher loading levels were necessary to create macrocracks. This cohesion leads to a higher compressive strength.

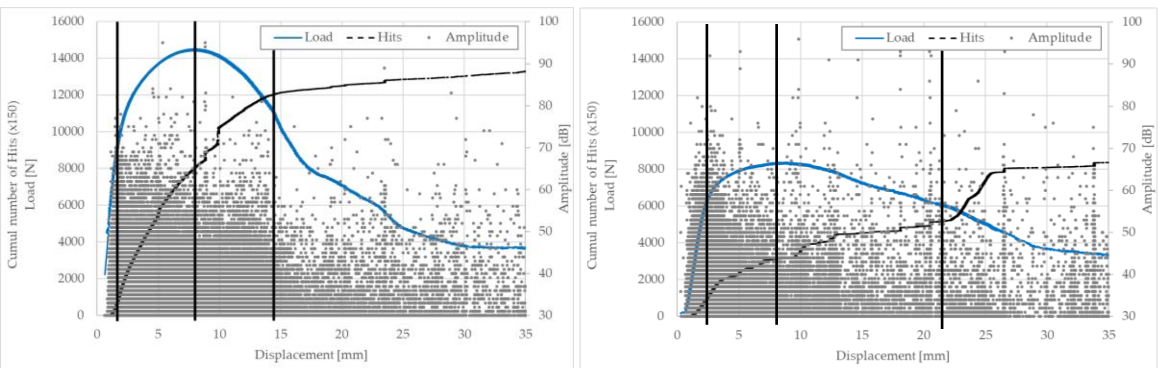

FIGURE 2. **Correlation between the load, the amplitude and the cumulative number of AE hits for flax and hemp concrete**

The AE localisation maps show that most of the AE events are located in the middle of the cylinders for the two concretes (Figures 3). The number of AE events is much higher for hemp concrete than for flax concrete. This indicates that the cracks created by the compression effect in hemp concrete are more abundant than in flax concrete.

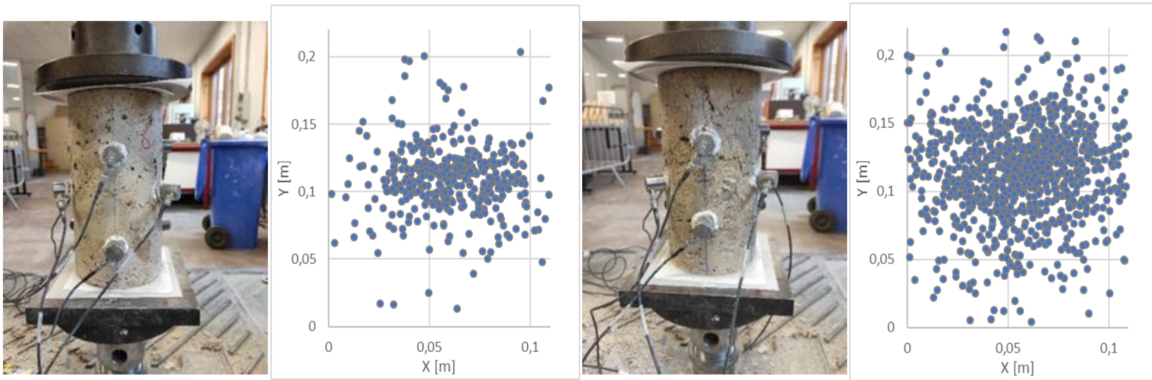

FIGURE 3. AE events localization maps for flax concrete (left) and hemp concrete (right)

CONCLUSION

In this paper, two bio-based concretes were monitored with the AE technique during a compression test. This first study showed the efficiency of the AE technique to monitor the damage evolution of those concretes and it was possible to analyse and highlight the differences in behavior between hemp and flax concretes. Flax concrete shows a delay in crack propagation in comparison to hemp concrete that shows a premature rupture for low loading level based on the cumulative number of AE events in correlation with the load-displacement curves. The perspectives are to study different types of bio-based concrete (in aggregate and binders) and to continue the data processing, especially in terms of frequencies and classification of AE sources.

REFERENCES

Amziane, S., Collet, F., Lawrence, M., Magniont, C., Picandet, V., Sonebi, M., 2017. Recommendation of the RILEM TC 236-BBM: characterisation testing of hemp shiv to determine the initial water content, water absorption, dry density, particle size distribution and thermal conductivity. Mater. Struct. Constr. 50, 1–11. https://doi.org/10.1617/s11527-017-1029-3

Fougy, F., 2020. Le lin : une filière d'excellence à l'épreuve de la Covid. L'Agriculteur normand.

Interchanvre, 2017. Plan Filière de l'interprofession du chanvre.

Kouta, N., Saliba, J., Saiyouri, N., 2021. Fracture behavior of flax fibers reinforced earth concrete. Eng. Fract. Mech. 241, 107378. https://doi.org/10.1016/j.engfracmech.2020.107378

Marceau, S., Glé, P., Guéguen-Minerbe, M., Gourlay, E., Moscardelli, S., Nour, I., Amziane, S., 2017. Influence of accelerated aging on the properties of hemp concretes. Constr. Build. Mater. 139, 524–530. https://doi.org/10.1016/j.conbuildmat.2016.11.129