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INFLUENCE OF BIORESOURCE ON MINERAL BINDERS HYDRATION AND VEGETAL CONCRETES COMPRESSIVE STRENGTH

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Plant-based concretes are increasingly being used as building materials thanks to their insulating properties and reduced environmental impact. However, the use of these materials is still limited by the lack of knowledge and the high variability of their performance which makes it impossible to predict their mechanical performance from their initial formulation [1].

This study presents results of a project which aims to control the mechanical performance of plant-based concretes and to define compatibility indicators between mineral binders and plant particles. The impact of aggregates from three plant species (bamboo, hemp shiv and rapeseed) on the hydration kinetics of two cements (CEM IV, a pozzolanic cement, and LC3, a limestone calcined clay cement) is evaluated by isothermal calorimetry and mechanical tests were carried out on plant-based concretes to determine their compressive strength.

The heat flow released by the hydration reactions and the cumulative heat are measured over time by isothermal calorimetry at 25°C (TA Instruments Tam-Air 8). The samples tested were cement pastes with a water/cement ratio (W/C) of 0.5 and a plant/cement ratio (V/C) of 0 for the reference samples and 0.02 for the mixes. The plants were grinded to obtain homogeneous mixtures for the small-volume samples and in order to maximize the interaction between these materials and make it independent of the morphological factors of the plant aggregates, such as shape and roughness. For each plant-cement couple, two main results are extracted (Figure 1): the position of the maximum heat flow value and the cumulative heat after 5 days.

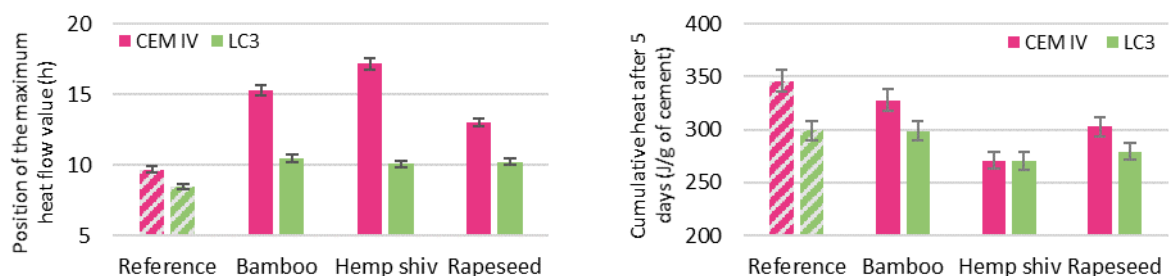


Figure 1 Position of maximum heat flow value and cumulative heat after 5 days for each couple of plant-cement

The addition of plants to cements leads to changes in heat curves, corresponding to delayed and longer reactions compared to pure cements, with a variation in the effect depending on the nature of

the plant and cement. The setting delay is about 2 hours for LC3 cement, whatever the nature of the plant. For CEM IV, on the other hand, it varies from 3 hours for rapeseed to 7 hours for hemp shiv, the influence of bamboo being intermediate.

Concerning the cumulative heat after 5 days, it decreases when plants are added to cement pastes. For LC3 cement, bamboo has no impact on this parameter, while the values achieved for hemp shiv and rapeseed are of the order of 92% of the heat of hydration of the binder alone. For CEM IV cement, the impact of plants is more significant, and the heat of hydration in the presence of hemp shiv, bamboo and rapeseed reach 79, 88 and 95% respectively of the heat of hydration of the cement without plant additions.

These results are generally attributed to plants constituents, such as sugars and phenols, both known for their retarding effect on the setting of cements [2]. In this study, we can also observe a different effect depending on the nature of the binder. Indeed, the plant compounds extracted may depend on the nature of the cement used. On the other hand, these different plant compounds interact differently with the anhydrous phases of the binders. Therefore, their impact depends on the chemical composition of the cement used [3].

Upscaling from cement paste to concrete is done to see if a similar impact of plants is visible on the performance of plant-based concretes. Specimens with dimensions of $150 \times 150 \times 150 \text{ mm}^3$ were produced following the formulation presented in Figure 2. As bamboo particles have a lower water absorption capacity than hemp and rapeseed particles, the V/C ratio was adjusted to maintain similar workability in the fresh state for all plant-based concretes. After one year of hardening and 28 days in a climate-controlled room (20°C and 50% RH), the mechanical properties of the specimens were characterized [4] and the compression strengths of the different concretes are reported on Figure 2.

Vegetal	Binder	W/C	V/C
Bamboo	CEM IV	1	1.7
	LC3		
Hemp shiv	CEM IV		0.5
	LC3		
Rapeseed	CEM IV		0.5
	LC3		

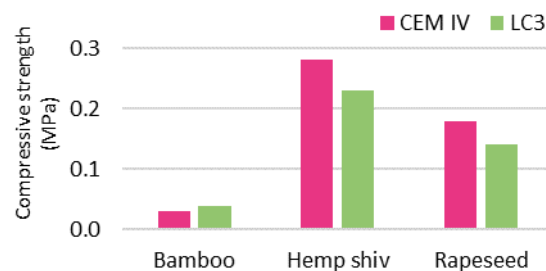


Figure 2 Formulation and ultimate useful compressive strength of plant-based concretes

The mechanical performances were the highest for hemp concretes and the lowest for bamboo-concretes for both binders. The low values observed for bamboo concretes may be linked to their different formulation: the plant-to-cement ratio V/C is 0.50 for hemp and rapeseed concretes, whereas it is 1.67 for bamboo concretes.

In order to understand the compressive strengths of plant-based concretes, which vary greatly depending on the type of aggregate used, the results obtained were compared with those obtained by isothermal calorimetry study. For these two studies at different scales, it was not possible to maintain the same plant/cement ratio, as the heat flux associated with cement hydration is not visible by isothermal calorimetry if the amount of plant added to the cement is too great [2].

The relationship between these results and those obtained by calorimetric measurements can be seen in Figure 3. The compressive strengths of plant-based concretes are related to the delay in the maximum value of heat flow value and to the decrease in cumulative heat at 5 days due to the presence of vegetal powders in cements.

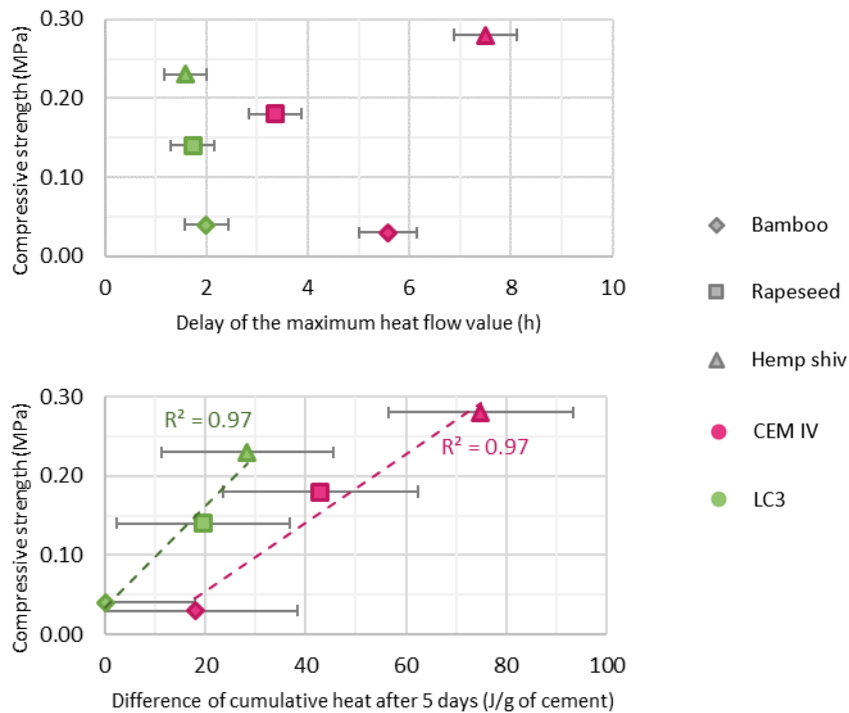


Figure 3 Compressive strength of vegetal concretes as a function of calorimetry results

For the cements and plants used in this work, there is a correlation between compressive strength and set retardation caused by plants in the case of LC3 cement, where the mechanical strength of plant concretes increases when the retardation due to the addition of plants decreases.

Indeed, certain organic extractives derived from plant aggregates, such as sugars and phenols, are known as set retarders, and for having an impact on mechanical strength [2, 5, 6]. According to these authors, these plant components act by complexation, particularly of calcium ions, thus forming organo-mineral compounds. This phenomenon is characterized by the confinement of Ca^{2+} ions resulting from the dissolution of cement grains by the hydroxyl and carboxyl functions of negatively-charged organic molecules in a basic environment. Thus, the formation of hydrates – responsible for the mechanical strength of plant-based concretes – is prevented, slowed or even inhibited by the formation of these organo-mineral compounds, depending on parameters that depend on the chemical composition of cements and plants. This relationship is not observed in the case of CEM IV cement, showing that all compounds extracted from plant particles do not have the same effect on the various chemical compounds in the binder.

Figure 3 also shows that the mechanical strength of plant-based concretes increases as the difference of cumulative heat decreases. These results indicate that the impact of plants on the hydration kinetics of cements with a mass ratio of only 2% can help explaining their influence on plant-based concretes containing a high quantity of plants. Nonetheless, the chemical composition of these plants is extremely complex and variable. This highlights the importance of studying variations in the chemical composition of these aggregates and their interaction with different cements. These analyses are currently in progress to enable the understanding of the results presented in this article and extend them to other types of material. Characterizing the plant compounds extracted during concrete processing is the essential step towards designing plant-based concretes with optimized mechanical properties.

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