Monitoring of ultrasonic pulse velocity for earth concrete properties evaluation - Effect of curing conditions

Duc Chinh NGO[1, 2], Jacqueline SALIBA[1], Zoubir Mehdi SBARTAÏ[1], Nadia SAIYOURI[1]

[1] *I2M, Université de Bordeaux, UMR 5293, CNRS, Bât A11, 351 cours de la libération, F-33405 Talence, France*

[2] *University of Transport and Communications, 3 Cau Giay road, Dong Da district, Hanoi, Vietnam*

RESUME This paper aims to study the effect of curing conditions on the mechanical properties of earth concrete. The studied earth concrete mixtures were constituted of different percentages of clayey and sandy soil with limited quantities of cement, lime and hemp fibers. Earth concrete mixtures have been cast and vibrated as normal concrete. Compression tests have been carried out on samples at different age and curing conditions. The ultrasonic non-destructive technique has been used for monitoring the hardening of soil concrete in function of the curing conditions. The results show that the Ultrasonic Pulse Velocity (UPV) decreases with the addition of clayey soil and hemp fibers. In addition, a good correlation has been observed between the compressive strength and the UPV and thus UPV can be used as an indicator for the evaluation of earth concrete mechanical properties.

Mots-clefs Earth concrete, Clay, Hemp Fibers, curing conditions, Ultrasonic

I. INTRODUCTION

Due to environmental concerns, development of alternative construction materials such as earth concrete are needed nowadays. This ecological concrete allows the reduction of the CO_2 production due to cement production, the impoverishment of resources and the energy consumption. In fact, soil is cost effective, locally available and recyclable with a low grey energy and good insulation properties. Earth concrete is usually stabilized by lime and cement to increase the mechanical and physical properties of the soil (Ngoc et al., 2020). Natural fibers as hemp fibers can be also added as they are naturally produced with low transformation energy and are a carbon-negative. In addition, it is renewable and environmentally friendly. The addition of fibers can also improve the insulation properties and decreases shrinkage and cracking of soil concrete due to the bridging effect of fibers (Kouta et al., 2020). However, more research is needed in order to have a better understanding of their mechanical properties and their durability.

The ultrasonic method is a nondestructive technique widely used in the literature to assess the young modulus and degradation of concrete. However, few studies have been conducted on earth concrete materials. This technique has been used in this study in order to have a better understanding of the ageing of earth concrete and more particularly the effect of conservation conditions. In fact, the mechanical properties of earth concrete can be highly correlated to the presence of water. The UPV can be also affected by the moisture content and the presence of fibers and can be used to evaluate mechanical properties.

The objective of this study is to monitor strength variation during three months of curing and to evaluate the relationship between the UPV and the mechanical properties of several soil concrete mixtures. The effect of two different cure conditions: quasi-saturated controlled relative humidity condition and ambient condition has been investigated.

II. EXPERIMENTAL PROGRAM

A. Materials and composition of earth concrete mixtures

The clayey and sandy soils have been stabilized, with cement and lime. Hemp fibers have been also added to increase the insulation properties. The soil was extracted from two local construction sites in Bordeaux and classified according to the Unified Soil Classification System (USCS). Clayey soil was characterized in laboratory by granulometric and sedimentation methods, Atterberg limits and methylene blue value (0.67) tests. They clearly indicate that the soil is "clayey with low plasticity" (Ip = 21.66 and Wl = 51.74%). The clayey soil mineralogy was also studied by X-ray diffraction (XRD) analysis. Additional information about soil characterization can be found in (Ngoc et al., 2020). A natural hydraulic lime and cement has been added to concrete mixtures. The non-hydraulic lime (100 NHL5) from Saint Astier product (France), is chosen in accordance with the European standard EN 459-1. The cement CEM V 42.5 N with a fineness of 4590 cm^2/g is chosen based on two different principal criteria: clinker ratio and CO_2 impact (table 1).

Table 1: Mineralogical composition of cement

Type of cement	Main components (% by weight)			Secondary component
	Clinker Portland	Blast furnace cinder	Fly ash	
CEM V/A (S-V)	40 - 64	18 – 30	18 - 30	0 - 5

Different soil concrete mixtures have been considered in which the percentage of clayey soil has been varied between 0% and 40% (0A, 20A, 30A, 40A) and the volume fraction of hemp fibers has been modified from 0% to 1.2% (0F, 0.6F, 1.2F). The effective water to cement ratio has been kept constant. Water has been added to take into account the water absorption by clayey soil and hemp fibers and to keep acceptable workability for the construction industry (slumps > 6 cm). 24h after casting, specimens have been removed from the molds and conserved in two different cure conditions: (C1) under a temperature of 20°C and relative humidity between 90% and 100% and (C2) in ambient condition at a temperature of 22°C and a relative humidity between 60 and 70%.

B. Compressive Tests

The unconfined compressive tests have been carried out on cubic specimens with dimensions of 10×10×10 cm^3 using an electromechanical machine with a capacity of 50 kN. The loading of concrete has been applied with a steel plate at a constant rate of 0.5 mm/min by means of a jack displacement.

C. Measurement of the Ultrasonic Pulse Velocity

A movable system composed of a pulse generator PUNDIT (Portable Ultrasonic Non-destructive Digital Indicating Tester) with a direct transmission mode has been used. A pulse of ultrasonic longitudinal stress waves with a frequency of 200 kHz was introduced into one surface of the concrete by a transducer coupled to the surface with a coupling gel. The pulse travels through concrete and is received by a similar transducer coupled on the opposite surface. The propagation velocity is calculated. Cubic specimens have been tested during three months (from the age of 5 days until stabilization).

III. RESULTATS ET DISCUSSIONS

A. Effet of curing conditions on the compressive strength

Figures 1 shows the comparison between the evolution of the compressive strength under ambient and controlled conditions at 7 and 28 days. The results show that the compressive strength increases with the age of earth concrete which could be related to different hydration reactions. However, it decreases with the percentage of hemp fibers and clayey soil. This could be associated to the lower density and the modification of pore size distribution by introducing voids and discontinuity (Kouta et al., 2020). The curing conditions showed a slight influence on the compressive strength. At 7 days, the compressive strength at ambient conditions is smaller for mixtures with 0% and 20% of clayey considering the different ratios of fibers. This could be associated to a better hydration and to the suction effect. In fact, the compressive strength depends on the attractive forces between the soil particles and water molecules. During drying, shrinkage strain pulls clay minerals closer which can increase the compressive strength when soil particles are in direct contact. However, the compressive strength of drying soil concrete is smaller for specimens with 30% and 40% of clayey soil. This may be due to the high rate of shrinkage when the volume fraction of clayey soil increased and to micro-cracking related to stress induced by desiccation.

(a) (b)

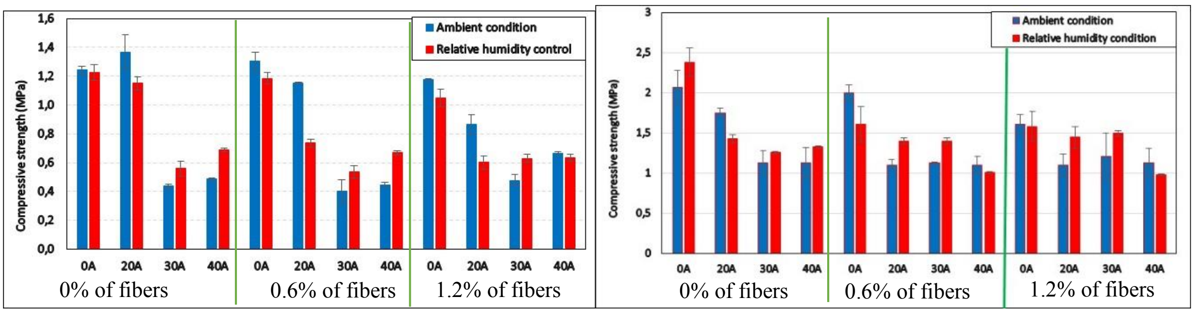

FIGURE 1. **Compressive strength of earth concrete specimens cured at ambient and controlled conditions at 7 (a) and 28 days (b)**

B. Monitoring of earth concrete using the ultrasonic method

The UPV of the mechanical P waves depends on the same parameters that influence the mechanical properties such as the density, porosity, and elasticity of the material (Mandal et al., 2016). The evolution of UPV in function of time shows two different shapes under the two cure conditions (Figure 2a). The UPV of specimens cured in controlled condition increased during the curing period with an important rate during the first days indicating that earth concrete develops mechanical strength at early age due the hydration reaction. After one month, UPV continued to increase slightly and the degree of saturation is important since the evaporation is limited. In addition, UPV increases with an important rate for soil concrete with 0% of clayey soil in comparison with mixtures with 20%, 30%, and 40% of clayey soil where the UPV decreases due to a higher porosity.

The UPV of earth concrete cured under ambient conditions increases with a much important rate during the first days of curing and then decreases due to desiccation to stabilize after 35 days. UPV decreases also with the addition of clayey soil with a clear difference between the different mixes. From 5 to 15 days, the UPV of soil concrete increases as the porosity decreases due to the hardening and the hydration reaction. The UPV reaches the maximum value earlier for mixes with a higher rate of clayey soil. From 15 to 35 days, the UPV decreases which could be due to water evaporation and desiccation of specimens. In fact, UPV is higher in solid media than through liquid and then gas. After 35 days, the UPV is constant due to the stability of concrete porosity, hardening process, and desiccation. Figure 2b shows the correlation between the compressive strength and the corresponding UPV values in controlled condition. An exponential function can be considered by a regression analysis. The results present a coefficient of determination of about $R^2 = 0.75$ that indicates a good correlation.

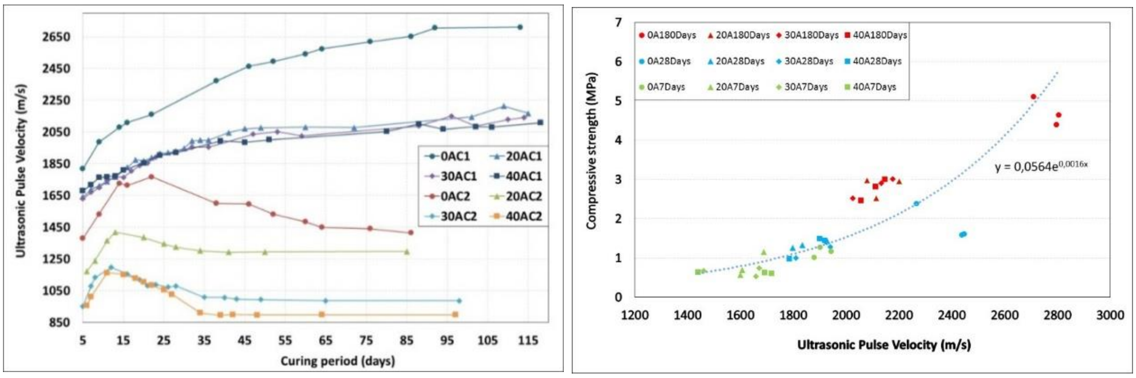

FIGURE 2. **Effect of curing conditions on UPV results (a), compressive strength vs UPV (b)**

B. Mercury Intrusion Porosimetry

Figure 3 shows the distribution function of pore volume for 20A0F, 20A1.2F and 0A0F. The pore size distribution range varies between 0.002 µm to 70 µm. From a dynamic point of view, the experiments take place from the right to the left i.e, large access radii (Washburn's law) towards small access radii. The distribution is largely dominated by a main mode centered at 0.7 µm and shift to the right with the addition of clayey soil and fibers. The results show a significant increase in the total porosity by adding 20% of clayey soil (38.77%) and a slight increase with the addition of 1.2% of fibers (38.16%) in comparison with the reference formulation (28.37 %) following the same trends as those obtained by porosity accessible to water tests. The pore size distribution shows the appearance of two secondary modes at 7.10-3 µm and 3 µm for the mixtures with 20% of clayey soil. The modification of the pore size distribution is thus responsible for the modification of the mechanical and transfer properties of the soil concrete.

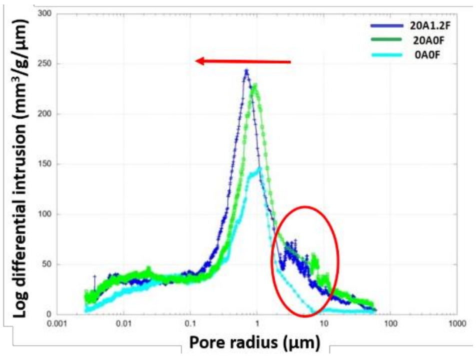

Figure 3 : Effect of clayey soil and fibers on pore size distribution.

IV. CONCLUSIONS

The effect of the percentage of clayey soil, hemp fibers and curing conditions on the mechanical behavior of earth concrete has been studied in this paper. The UPV have been continuously measured in function of time and for different curing conditions. The UPV results show a good correlation with the compressive strength and decreases with the addition of clayey soil and hemp fibers due to the higher porosity as has been shown with mercury intrusion porosimetry. Thus, UPV can be used as an indicator to evaluate the mechanical properties. The effect of curing conditions on the UPV shows different phases due to water content, hydration reaction, pore structure and damage due to drying. Additional tests will be realized in the future to increase the reliability of UPV results and take into account the effect of water in combination with other parameters as attenuation and non-linear features for a better qualitative evaluation of earth concrete mechanical properties.

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