Characterization of tunnel excavated earth-based mortars for rammed earth repair

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Abstract. The aim of this work is to study the possibility to reuse the tunnel excavated earth in order to elaborate earth-based mortar for rammed earth reparation. The tunnel excavated earth-based mortars were compared with raw earth based-mortars, largely used in practice. The cement was used as stabilizer and the hemp fibers were used to diminish the cracking due to shrinkage. The mechanical, thermal and hydric properties of mortars were characterized after 28 days. The mortars were maintained in hydrothermal chamber at controlled conditions, 20 ± 2 °C and 50 ± 5 HR. The obtained results show that the mechanical performances increase with the increase of cement by earth ratio. While, the increase of cement content affects negatively the thermal conductivity of earth-based mortars. Whereas, the thermal properties were improved with the addition of natural fiber. The excavated earth-based mortars show higher mechanical performances and good thermal properties compared to raw earth-based mortars.

1 Introduction

The Grand Paris Express project, an extraordinary project from a technical point of view, has significant environmental consequences. As a matter of fact, 45 million tons of earth will be extracted over the duration of the works. Our objective is to propose alternative solutions to valorize these huge quantities of excavated earth (ExE).

Several research works have been carried out to valorize the local excavated soil resulting from surface earthworks in order to elaborate earth-based mortars, rammed earth construction, plaster for masonries walls, earth blocks, … [1] [2]. Many binders were tested as stabilizer such as Portland cement, natural cement, hydraulic lime, hydrated air lime [3] [2]. Some fibers such as hemps fibres, coconut fibres, natural fibres were tested in order to diminish cracking by shrinkage of clays existing in earth material [4] [5]. On the other hand, little work has been done on the tunnel excavated earth. The only research found on the excavated earth is that of Voit and Zimmermann (2015) [6]. In their research, they used only the gravel excavated from tunnel excavated as a substitute for natural aggregates to produce concrete.

The main aim of this paper is to study the efficiency of using tunnel excavated earth (ExE) by comparison to raw earth (RwE) in order to elaborate earth-based mortars.

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2 Materials and method

The earth used in this work comes from the tunnel digging work as part of the Grand Paris Express Project. The excavated earth was supplied by TRACTEBEL-ENGIE company. While the raw earth was supplied by IUT GC-CD, CY Cergy Paris University. The Atterberg limits and methylene blue value results show that the excavated earth is clayey sand A-2-6 and the raw earth is considered as fine sand A3 according to AASHTO soil classification. At first, an attempt to manufacture mortars using only excavated earth has been tested. The earth mortar obtained is very fragile and sensitive to water, therefore the use of stabilizer additives is unavoidable. Cement was used as binder to elaborate tunnel excavated earth-based mortars. Naturel short hemp fibers, with average seize of 0.5-2.5 cm and density of 105 kg/m3, was used as reinforced fibers to diminish shrinkage of earth-based mortars. The excavated earth is a mixture of water (16%), fine particles <63 µm (27.3%), sand 0.063-4 mm (52.8%) and some gravel 4-20 mm (3.9%). The small gravel portion has been removed from the excavated earth in order to elaborate earth-based mortar. The effect of hemp fibers addition and stabilizer (cement) on the thermal and mechanical properties of earth-based mortars are investigated. The shrinkage and the capillary water uptake were also studied. All mortars were maintained at controlled conditions using a hygrometric chamber, 20 ± 2 °C and 50 ± 5% RH. Several formulations of mortars were adopted (table 1).

Table 1: Formulations of earth-based mortars

% by weight	Excavated earth				Raw earth	
	M0	M1	M2	M3	M4	M5
Earth (E)	69.6	68.8	66.8	64.8	69.6	68.8
Cement (C)	5	5	7	9	5	5
Total water*	25	25	25	25	25	25
Superplasticizer	0.4	0.4	0.4	0.4	0.4	0.4
Hemp fibers	-	0.8	0.8	0.8	-	0.8
C/E	-	0.07	0.10	0.14	-	-
* including the water present in the excavated earth						

3 Results and discussions

The characterization at fresh state (Fig.1) of excavated earth-based mortars and raw earth-based mortars show that the workability of ExE based mortars decrease with the increase of cement by earth ratio. The raw earth-based mortars present higher workability compared to ExE based mortar for the same water content indicated that the excavated earth need more water to reach the same workability as the raw earth, explained by the different nature of earth, clayey sand A-2-6 for ExE and fine sand A3 for RwE. The natural hemp fiber shows no considerable effect on the consistency of ExE based-mortars (M0 vs M1). However, there is a significant effect of hemp fiber on the RwE based-earth workability.

The obtained results show that the mechanical properties of ExE-based mortars increase with the increase of cement by earth ratio (C/E) (Fig.2). The hemp fiber addition shows no considerable effect on the ExE-based mortar mechanical's performance. ExE-based mortars present higher performances compared to RwE-based mortars. The compressive strengths of all earth mortars exceed the limit values required by the specifications of the DIN 18947 standard (>0.5 MPa). However, for the flexural strengths only the mortars elaborated with 7 and 9% of cement are exceed 0.2 MPa, the minimum required by the same standard.

As for the thermal properties (Fig.3), the increase of C/E ratio affect negatively the thermal conductivity but present a good effect on the thermal inertia of ExE-based mortars. The hemp fibers addition shows a positive contribution to the thermal properties of mortars.

ExE-based mortars show also good thermal properties relatively to RwE-based mortars. Compared to cement mortars and plaster mortars, largely used as thermal insulation materials, the ExE-based mortars show better thermal performances

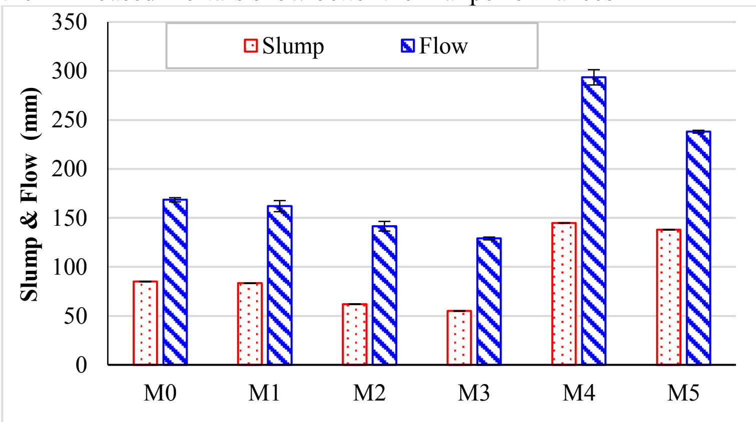

Fig. 1: Slump and flow consistency of earth mortars

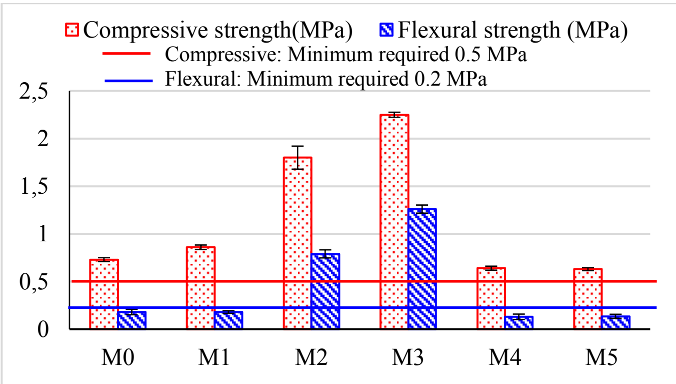

Fig. 2: Compressive strength, flexural strength and dynamic modulus of earth based-mortars

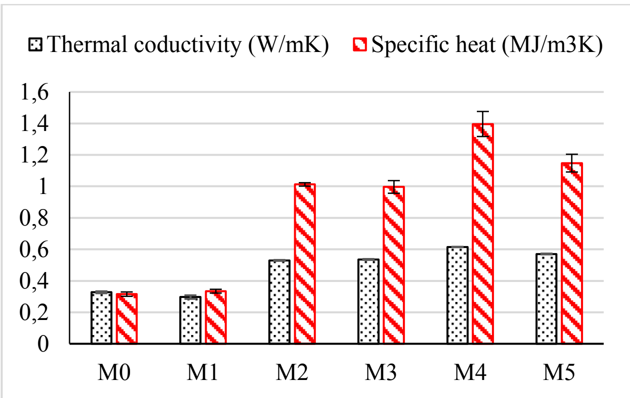

Fig. 3: Thermal properties of earth-based mortars

The kinetics of water absorbed by capillarity and capillary absorption coefficient of earth based-mortars are investigated (Fig.4). The results show that the absorbed water and capillarity coefficient decreases strongly with the increase of C/E ratio. The samples with hemp fibers absorb more water, with time, compared to those without fibers indicating that fibers particles absorb an amount of water for both ExE and RwE based-mortars. The results show also that the RwE based mortars show higher water absorbed and capillary coefficient with time comparative to ExE based mortars.

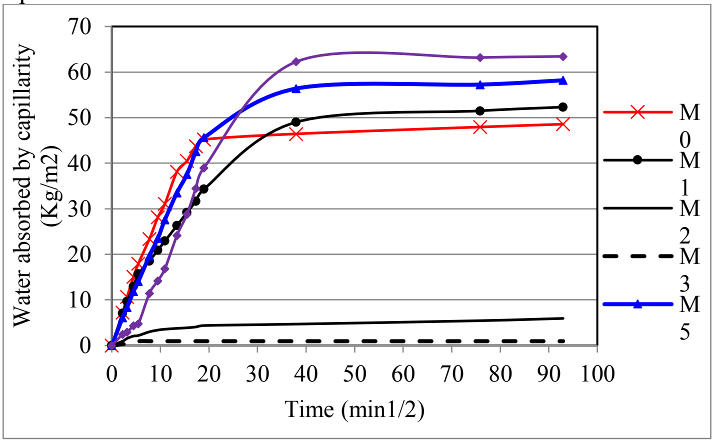

Fig. 4: Water absorbed by capillary of all earth based-mortars

4 Conclusions

The results obtained are promising and show that the tunnel excavated earth-based can be considered as novel efficient earth mortar and used as repair materials and thermal insulators meeting environmental requirements. Experimental work is in progress to study the compatibility between ExE based mortars and different types of masonry walls.

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