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The influence of soil content on the mechanical properties, drying shrinkage and autogenous shrinkage of earth concrete

Jean Marc Kanema

Laboratoire Ondes et Milieux Complexes CNRS UMR 6294, Université du Havre53 rue Prony, 76600 Le Havre, France

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ABSTRACT

Earth concrete is increasingly used for the construction of buildings and other civil engineering structures, yet little data are available to date describing the shrinkage of this building material. The present experimental study evaluates the behavior of four concrete mixtures containing different quantities of soil and presenting various water/cement ratios. Earth concrete samples were cast then stocked at normal room temperature and humidity levels. Tensile strength, modulus of elasticity, one directional shrinkage and X-ray diffraction were measured in all samples. The results indicate that the storage conditions and soil content of earth concrete influence the mechanical behavior and shrinkage of this building material.

1. Introduction

Eco-building is an increasingly important concept in the field of construction. A limited environmental impact is sought by using materials produced in such a way as to ensure the lowest possible amount of greenhouse gas emissions. A building material made from soil and recycled aggregates can be an appropriate answer to this recent demand.

However, studies carried out on the use of recycled aggregates in the construction field have pointed out that the partial or total substitution of conventional aggregates by recycled aggregates in the concrete led to a decrease in compressive strength [1–6], modulus of elasticity [1] and density [5,7], whilst drying shrinkage increased [4,8,9]. To explain this behavior, several authors [2,3,6,8,10] suggest that the high porosity of the mortar clinging to aggregates could absorb great amounts of water and thus lead to an increase of shrinkage. This theory appears to be corroborated by the work of Corinaldesi [11], Fathifazi et al. [9] and deBrito et al. [7], who show that a good formulation method would be the key to limiting the loss of compressive strength and reduce the extent of drying shrinkage.

Other works carried out by Tazawa [12,13], Jensen [14], Zhang [15], Lura [16] revealed autogenous shrinkage increased with the reduction of the water cement ratio [12,14,15], and decreased when greater amounts of aggregates were added [13]. These authors emphasize that the extent of endogenous shrinkage is directly linked to the structure and distribution of pores in the dough [14,16,17].

Studies carried out to understand the behavior of soil throughout drying have shown its strong tendency to shrink and crack. They highlight that the cracking of the soil depends on its nature and the quantity of clay elements it contains [18]; higher proportions of clay elements result in a higher occurrence of shrinkage. These authors also indicate that much of the cracking takes place while the soil is still saturated and the evaporation rate of water is constant [19–21].

In the Normandy region of France, a material composed of soil and recycled aggregates is currently being used to construct buildings. Unlike earlier products such as rammed earth, this new material is poured into the formwork then vibrated like a conventional concrete. This technique allows the rapid removal of formwork and therefore increases productivity. However, this new material called Cematerre (marketed by Lefebvre Industrie SA-Cematerre) displays a strong tendency to crack, probably due to drying shrinkage in the cement-based materials.

To the best of our knowledge, very few studies to date have investigated the behavior of earth concrete materials such as Cematerre. Our previous study [22] demonstrates that the compressive strength, tensile strength and Young's modulus of earth concretes are far below than those of conventional concretes. The same article also highlights that the distribution of pore size in the earth concrete is one of the main factors involved in shrinkage. The final shrinkage observed in earth concrete, after 90 days of drying, is substantially greater than that observed in conventional concretes.

To continuous this work and improve the knowledge of autogenous shrinkage and the chemical compounds making up earth concretes, we created four different formulations of concrete, replacing part of the soil with recycled aggregates. Some of the resulting samples are protected from drying, while the others are allowed to dry at room temperature.

E-mail address: kanematm@univ-lehavre.fr.

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Table 1
Components of the formulations.

Components	Soil (kg/m^3)	RCA (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Adjuvant (dry particle) (kg/m^3)	Density (kg/m^3)
EC-0%G	1385	0	138	414	1.65	1939
EC-7%G	1181	313	138	400	1.65	2034
EC-19%G	918	645	138	374	1.65	2077
EC-31%G	675	946	138	358	1.65	2119

The responses of the different compositions are evaluated by bending, wave propagation, X-ray diffraction and unidirectional shrinkage tests. The results enable us to judge the behavior of a material composed of recycled aggregates and soil when subjected to external and internal drying.

2. Materials and preparation of samples

2.1. Concrete mixture proportions

The four concrete compositions tested in this study were created using the Dreux-Gorisse formulation method [23]. They contained recycled aggregates at volumes varying from 0% to 31%, and all four samples contained a cement dosage of 138 kg/m^3. The concretes containing 0% of recycled aggregates is hereafter referred to as EC-0%G, and the concretes containing 31% of recycled aggregates are called EC-31%G. The amount of water and superplasticizer are introduced in order to ensure good workability of the concrete during casting. The high water-reducing superplasticizer (adjuvant) has a pH of 4, and contains practically no chloride ions (Cl- < 0.1%) [24]. The four compositions tested are described in Table 1.

The granular skeleton of our samples is composed of recycled aggregates and soil. The latter is natural soil which initially has a similar appearance to garden soil. Up to 3% of the dry soil weight is replaced with lime (CL 90-Q), and the resulting mixture is identified as SL following the LPC-USCS classification (ASTM 2487-11). The soil contains practically no clay, 25% silt and 67% fine sand. These properties are summarized in Table 2.

Recycled aggregates come from the construction industry. They result from the crushing of concrete blocks after the removal of reinforcing mesh. The grading curves of the soil and aggregates are shown in Fig. 1.

The concrete doughs are made with cement CEM I 52.5. The chemical and mineralogical constituents of this product are shown in Tables 3, 4.

The curing compound used in this study is Sika Antisol E-40 [25]. It has a density of 0.989 and a pH of 5. This product was directly applied to the sample surface using a spray.

Table 2
Soil properties [48].

Methylene blue test value: VBS	0.5
Liquid Limit: W_L (%)	20
Plasticity Index: IP	6
Grain distribution	
Fine particle content (< 80 μm) (%)	35
Clay (< 2 μm) (%)	0
Silt (2–60 μm) (%)	25
Sand (0.06–2 mm) (%)	67
Gravel (> 2 mm) (%)	8
Effective size D_{10} (μm)	32
Uniformity coefficient $C_u = \frac{D_{60}}{D_{10}}$	7.7
Coefficient of gradation $C_c = \frac{D_{30}^2}{D_{60} * D_{10}}$	0.78

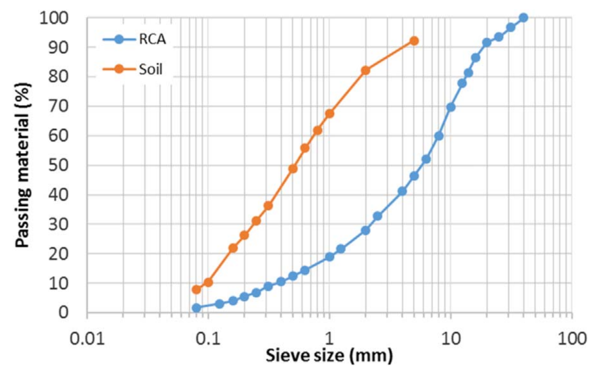

Fig. 1. Grain size distribution curves of the recycled aggregates and a soil.

Table 3
Chemical composition of cement (Technical sheet) [49].

Components	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	SO3	Cl⁻
Percentage	20.8	5.3	2.1	66.2	1.14	0.29	0.18	3.4	0.03

Table 4
Mineral composition of cement (Technical sheet) [29].

Components	C3S	C2S	C3A	C4AF
Percentage	65	12	12	6

2.2. Kneading protocol

The natural soil is extracted then mixed with lime to reduce its natural water content and change its texture. It is then stored in air contact to continue drying for at least one week.

At the moment of casting, the dry soil, recycled aggregates and cement are placed in a tray and kneaded manually for six minutes. Ninety percent of the mixing water is then added, and the mixture is kneaded for three minutes before the addition of the remaining 10% of water and the superplasticizer. The mixing time is extended by a further three minutes. When the mixture is homogeneous, it is poured into a 7 × 7 × 28 cm metal mold in three layers of equal thickness. Each layer is manually vibrated by way of sixty shocks to the metal mold. Once the preparation is completed, the specimens are cleaned, covered with plastic film to protect them from desiccation, and finally stored at room temperature and humidity.

3. Methods

Twenty-four hours later, the concrete samples were removed from the molds, cleaned and divided into two batches. Each batch was comprised of three samples from each concrete type. The first batch was used to track autogenous shrinkage and the second to monitor the total shrinkage.

The samples of the first batch were sprayed with curing agent, then packaged in a plastic film and covered with aluminum tape to protect them from light and finally marked for identification. The second batch