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Shrinkage of earth concrete amended with recycled aggregates and superplasticizer: Impact on mechanical properties and cracks

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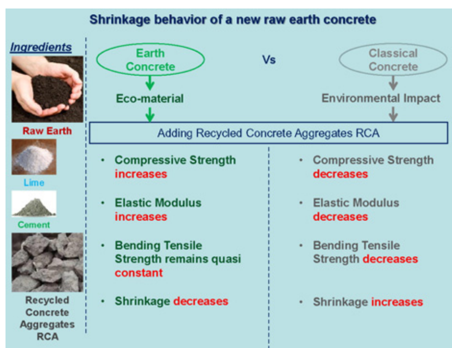
HIGHLIGHTS

- Shrinkage of new raw earth concrete is affected by adding recycled concrete aggregates (RCA).
- Adding RCA reduces shrinkage kinetic and limit and increases the compressive strength.
- Vibration has an impact on pore diameter distribution.
- Superplasticizer reduces crack appearance but not the global shrinkage.

GRAPHICAL ABSTRACT



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ABSTRACT

The study investigates shrinkage behaviour of a new earth concrete amended with various volume percentages of recycled concrete aggregates (RCA). Two preparations techniques, in situ (industrial) and laboratory (manual), were used. Shrinkage was evaluated using a one-dimensional method and a 2D image analysis. Shrinkage decreases with RCA percentages. Industrial vibration has also an impact on shrinkage. Adding superplasticizer reduces crack appearance without affecting the global shrinkage. Mechanical tests were performed to evaluate the impact of RCA. Compressive strength increases with the addition of RCA, and the bending tensile strength remains quasi constant.

1. Introduction

Concrete is the most used building material nowadays. Today, ecological and economic problems are taking increasingly predominant places, and it becomes difficult to continue exploiting materials (cement, sand and natural aggregates) in the same way as it was done before. It is now important to find reliable alternatives to replace sand and natural aggregates, in order to reduce their environmental impact. The use of construction materials based on "raw earth", like "earth concrete", consists a part of the alternatives.

A new earth concrete based on raw earth material (≈80%), mixed with binders (lime and cement), was developed and patented in Normandy, France. This new concrete is different from the traditional method of rammed earth (pisé), because it is cast into formworks like the classical concrete. The advantage of this technique is that it gives an industrial type of cadence, 1 h/m^2 for earth concrete and 6 h/m^2 for pisé. In a previous study [1], we showed that this new material tends to

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shrink and it is detrimental to its quality. This new raw earth building material is under constant development. Adding recycled concrete aggregates (RCA) can have two impacts: improving its strength while remaining very ecologic and reducing its shrinkage.

Several researches studied the influence of the substitution of natural aggregates by RCA in classical concrete [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12]. They showed that this substitution (i) reduces the compressive strength [6] [9] [13] [14], (ii) weakens the elastic modulus [6] [9] [13], (iii) reduces the density [2] [6] [14] and (iv) increases the shrinkage of the concrete [4] [5] [6] [7] [8]. The high water absorption of RCA is one of the parameters used to explain the high shrinkage of concrete containing RCA compared to classical concrete [7]. Meyer [14] showed that the fine particles (<2 mm) present in the RCA increase the shrinkage of the concrete. Others [2] [9] [10] explained that the amount of anhydrous mortar hooked to the aggregates is the main parameter controlling the shrinkage. Fathifazl et al. [8] proposed a new composition method to reduce the shrinkage of concrete containing RCA. Substituting natural aggregates, up to 30% of volume replacement, with RCA has a negligible impact on shrinkage and compressive strength [3] [9] [10].

Raw earth based materials present a high shrinkage and a tendency to crack during drying [15] [16] [1] [17]. They stated that the magnitude of shrinkage depends on the amount of clay present in the soil, and that the drying process is related to the maximum radius of the pores filled with water. The soil cracks when it attains its maximum tensile stress [15] [17]. Cracking modifies soil transfer and mechanical properties, and it appears in the beginning of desiccation while the soil remains quasi-saturated.

However, the theoretical study of Pickett [18] on a bi-phasic concrete can predict the evolution of the shrinkage. The work was pursued by other researchers [19] [20] [21] who showed that as the volume of aggregates added to a paste of concrete increases, the elastic modulus increases too while the shrinkage of this paste decreases. According to this theory, in our study we replaced a part of the fine raw earth skeleton by recycled concrete aggregates RCA.

In the literature, there is an absence of studies that show the effect of RCA on mechanical properties and shrinkage in "earth concretes". In this paper, initially we explain the composition of the raw earth concrete along with binders and superplasticizer. Then, we explain the experimental setup along with the different measurements. Finally, we discuss the reduction of shrinkage by adding RCA, improvement of mechanical properties and the impact of superplasticizer on cracks.

2. Materials

2.1. Raw materials

2.1.1. Soil and RCA

The natural soil used is retrieved from earthmoving works. It is classified as silty sand SL(SM) according to LCPC-USCS classification (ASTM D2487 - 11). Table 1 present its properties.

Table 1
Soil properties [43].

Methylene blue test value: VBS	0.5
Liquid Limit: W_L (%)	20
Plasticity Index: IP	6
Grain distribution	
Fines content (<80 μm) (%)	35
Clay (<2 μm) (%)	0
Silt (2 μm to 60 μm) (%)	25
Sand (0.06 mm to 2 mm) (%)	67
Gravel (>2 mm) (%)	8
Effective size D_{10} (μm)	32
Uniformity coefficient $C_u = D_{60}/D_{10}$	4.37
Coefficient of gradation $Cc = \frac{D_{30}^2}{D_{60} * D_{10}}$	0.94

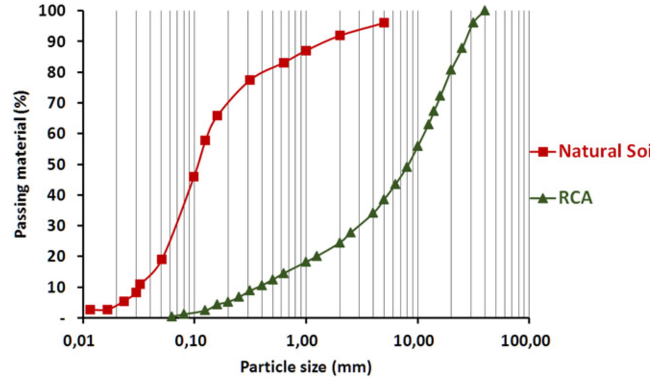

Fig. 1. Grain distribution: natural soil and RCA.

RCA consist of a recycled concrete aggregates, sorted, crushed and cleaned from steel bars. They are like gravels with granularity varying from 0 to 31 mm. They contain 25% of fine particles (<2 mm). Fig. 1 presents the particle size distribution for the natural soil and the RCA.

2.1.2. Binders: cement and lime

The lime used in this experiment is a calcic lime CL 90-Q, consistent with the Standard EN 459-1.

The used cement is CEM I 52.5 N. It meets the requirements of the standard NF EN197-1, NF P15-318 and NF EN196-10. Its mineralogical composition is summarized in Table 2. Mechanical resistance to simple compression short and 28 days are summarized in Table 3.

2.1.3. Superplasticizer

The superplasticizer called "Tempo 10" is a high range water reducing admixture. Its technical data is resumed in Table 4. Several tests were performed in order to select the admixture which is able to better reduce the shrinkage in this new raw earth material concrete. "Tempo 10" was the most suitable. It was added up to 1.48% ± 0.01 of the weight of mixing water added in order to obtain a good workability and to ensure a slump S3 (100–150 mm) according to EN 206-1 recommendation.

2.2. Specimens preparation

2.2.1. Concrete mixture proportions

Five formulations are tested varying the volume ratio of RCA in the mixture skeleton. The formulations were elaborated according to the French method of "Dreux-Gorisse" [22]. The RCA/Skeleton ratio varied from 20% to 57%; the different formulations were identified with a G

Table 2
Mineralogical composition of cement [44].

Main components	Percentage (%)
C_3S	65
C_2S	12
C_4AF	6
C_3A	12

Table 3
Compressive strength of the cement [44].

Strength class	Compressive strength (MPa)			Start of setting time (min)
	Early strength		Common strength	
	1 Day	2 Days	28 Days	
52.5 N	20.5	33.2	67	137