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Review

Mix design method for plant aggregates concrete: Example of the rice husk

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HIGHLIGHTS

- A rational method is proposed for the mix design of plant aggregates concrete.
- The volume of air trapped in this type of concrete is very important.
- We cannot ignore such a quantity of air in any formulation process.
- The volume of air depends only on the mixing time and the mode of implementation.

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ABSTRACT

This article proposes a method for the mix design of concretes based on plant aggregates. Its principle consists in determining the packing density of the plant skeleton for a specific mode of implementation and then in proportioning the binder paste which will occupy the residual intergranular pore volume. The paste is consisted of the binder, the effective water, the possible additions and admixture, and trapped air and/or entrained air. For a given volume of air (and additions), the quantities of cement and effective water are then adjusted to achieve the targeted performances, based on the law of Féret. However, for this type of concrete, the large volume of entrained air (also) depends on the quantity of cement and water present in the mixture, the intensity of the mixing and the casting mode. A model describing the residual air volume must then be calibrated from tests carried out with the components of the concrete that it is desired to manufacture. The problem of the formulation can then be solved by using a numerical optimization module. An example applied to a rice husks concrete is presented here.

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1. Introduction

Everyone agrees today that human activities significantly impact the climate of the planet [1]. The construction sector is one of the main contributors to this situation as it is the largest energy consumer and the second largest CO_2 emitter in the world [2–6]. It is therefore important to build eco-friendly buildings, which consume little energy and emit less greenhouse gases throughout their life cycle. Concretes incorporating plant particles are then of great interest because they are renewable materials and are easily recyclable. They also preserve the comfort and health of users [6].

A lot of studies has already been done on the association of hemp [7–17], wood [18–22], flax [23,24], rice husk [25–27] or rice straw [28] to mineral matrices. They generally show the interest (thermal, mechanical ...) of these products. However, the exploitation or comparison of the results is often difficult, due in particular to the diversity of the compositions resulting from always different mix design methods, depending on the objectives of the study, and sometimes based on erroneous assumptions. Some examples are given below.

Mougel [29], in a study on wood mortars, used a mix design method based on the density of the components of the mixture. He then fixed the density of the final mixture at 700 kg m^{-3}. The chosen cement dosage is 350 kg m^{-3} of dry wood aggregates. The quantity of water is determined by taking account of the appearance of the mixture. A contribution of water of 400 kg m^{-3} of dry wood was finally retained.

Nguyen [30] determined the quantities of the various constituents of the mixture by varying the mass ratios Binder (L)/ Aggregates (G), Water (E)/Binder (L) and the initial density of the specimen for 1 Cubic meter of hemp concrete from the relation (1):

$$\begin{cases} G + L + E = \rho_{initial} \\ G = \frac{\rho_{initial}}{1+\frac{L}{G}+\frac{E}{L}\times\frac{L}{G}}(Kg \cdot m^{-3}) \\ L = \frac{L}{G} \times G(Kg \cdot m^{-3}) \\ E = \frac{E}{L} \times \frac{L}{G} \times G(Kg \cdot m^{-3}) \end{cases} \quad (1)$$

In their studies of a clay-cement-wood composite, Bouguerra [31] et Ledhem [32], fix cement dosage at 25% of the mass of the wood + clay + cement mixture. They obtain several configurations by varying the mass fraction of wood relative to the wood-clay mixture. Water dosage is calculated using the following relation suggested by Al Rim [33]:

$$E = 0,35 \times C + 0,70 \times A + w_f \times F + k \times B \quad (2)$$

E, C, A, F, B are the masses of water, cement, clay, fines and wood respectively

W_f and k are respectively the coefficients determining the water required for wetting fines (W_f = 0.25 for shale) and wood shavings. The coefficient k takes into account the initial water content of the shavings and their water content at saturation.

Doko [34], in a study on rice husks concrete, used the absolute volume method. Knowing cement dosage per cubic meter of concrete, he varied the ratio of water to cement. The absolute volume of the concrete is given by the following expression:

$$V_{abs\,mixture} = V_{abs\,cement} + V_{abs\,saturated\,rice\,husks} + V_{abs\,water} \quad (3)$$

Akkaoui [6] proposed a mix design method whose principle is to use wood aggregates to their maximum compactness. The quantity of aggregates in the concrete is considered equal to the maximum of aggregates that can be introduced into it without needing a compacting machine. This principle integrates the assumption according to which the binder does not modify the compactness of the aggregates, which implies that the quantity of binder is not sufficient to fill inter-granular porosity. The apparent volume of its granular skeleton therefore defines the volume of the concrete V_b. This volume is composed of a volume V_g of wood aggregates, a volume V_{pdc} of cement paste, and a volume V_p of the intergranular pores. The absolute volume Vg of the aggregates is the product of the volume V_b by the compactness C_g of the aggregates. The mass B of the aggregates is defined by:

$$B = \rho_{abs} V_b C_g \quad (4)$$

The volume V_{pdc} of the cement paste is equal to the sum of the volume V_c of cement powder and the volume of mixing water Ve:

$$V_{pdc} = V_c + V_e = \frac{C}{\rho_c} + \frac{E}{\rho_e} \quad (5)$$

C and E are respectively the cement and water masses. The W/C ratio is set at 0.5 and four Cement/Wood (C/B) ratios have been chosen: 1.25; 1.75; 2.25 and 2.75. The volume V_p occupied by the pores between the aggregates (intergranular porosity) is equal to the void volume between the particles of the granular skeleton decreased by the volume V_{pdc} of the cement paste:

$$V_p = V_b(1 - C_g) - V_{pdc} \quad (6)$$

These examples show that practices are often empiricist, and that there is no truly consensual approach. It should also be noted that no method takes account of the trapped air in the mixture, whereas its volume may be very high in the presence of certain plant aggregates. Finally, none of the different inventoried methods incorporates the compressive strength of concrete as one of the formulation objectives.

We present here a more rational method for the mix design of concretes of plant aggregates that avoids as far as possible the pitfalls reported previously. It was tested on rice husks concretes.

It should be remembered that the rice husk is the residue of rice husking, which makes it possible to process the harvested rice or "paddy rice" into whole rice or "cargo rice". The proportion of rice husks is between 17 and 23% (of the total weight), depending on the variety of rice. Currently, the rice husk is often calcined at over 700 °C. The pozzolan ash thus obtained has already been the subject of much research [35–39]. Other works have been interested in the addition of rice husks in traditional concretes in partial substitution of sand and/or gravel [40–42]. Some work has involved the development of composites formed solely of rice husks associated with a mineral binder [43,34].

2. Materials and methods

2.1. Rice husk

The rice husk used in this study comes from the Zinvié hulling plant in Abomey-Calavi (Benin). It is a siliceous waste (up to 25%)