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A new methodology for determining particle density and absorption of lightweight, normal-weight and heavy weight aggregates in aqueous medium

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HIGHLIGHTS

- The surface absorption causes doubts in determining particle density.
- The methodology used to obtain water absorption according to standard causes uncertainty.
- The new method of obtaining absorption is more accurate and less susceptible to handling.
- The pycnometer method (determined by mass) shows problems.
- The differential mass proposed solves the disadvantages caused by the pycnometer method.

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ABSTRACT

Surface water absorption affects the value of the particle density obtained according to the UNE 1097-6. The aqueous medium absorption according to the standard poses problems as much in coarse fraction as in fine fraction. This new methodology is proposed in order to solve the problems observed in the current standard. The method is validated experimentally applying it to 5 different lightweight aggregates, 2 limestone normal-weight aggregates and a heavyweight aggregate. Different initial water contents and evolution of water absorption up to 28 days were analyzed.

1. Introduction

1.1. Background

The current standards, including UNE EN 1097-6 [1], for determining the dry particle density and the water absorption take as a reference the mass of the aggregate with saturated surface-dry condition. In our opinion it favors to obtain different values from those that would be obtained with an absolutely dry aggregate.

It is well known that aggregates in general and lightweight aggregates in particular tend to absorb a significant quantity of mixing water when they are dry, requiring additional water to maintain the workability of lightweight concrete at acceptable levels [2]. Therefore, there are many researches in which lightweight aggregates are pre-soaked or pre-wetted in order to have greater control over the workability and effective water content in concrete [3,4]. In addition, this absorption affects the density and design of concrete as well as the properties of both the fresh and hardened [5–8]. Obviously, if aggregates are totally saturated, they do not absorb water, while net absorption in aggregates is less when its moisture content is between the two states described [9].

Aggregate absorption, especially lightweight expanded clay aggregates, is mainly affected by its surface characteristics, particularly the quality of the outer shell crystallization and its roughness [10,11]; its microstructure: porosity and pore connectivity [12]; percentage of broken particles [11,13,14]; initial water content [9]; degree of cleanliness; environmental temperature and humidity, etc.

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Absorption of the aggregates in an aqueous medium can be determined by several methods specified in standards: the paper towel method, the cone test [1], and according to new methodologies proposed by several authors [15–17].

This research is focused on the standard UNE EN 1097-6 [1] commonly used to characterize the water absorption in coarse aggregates (cloth method) and fine aggregates (cone test).

1.2. Comments to the standard UNE EN 1097-6

In order to quantify the particle density with current standard UNE EN 1097-6, from our point of view, an anomaly is produced by considering the mass of the aggregate with different states of moisture content.

The current standard considers the mass of the aggregate saturated surface-dry condition (M_{ssd}) for determining the particle density of the aggregates (ρ_{rd}), which we believe tends to an **underestimation** or **overestimation** of the particle density. Due to the incidence of the variability of superficial absorption of the aggregates.

Indeed, by analyzing the current standard mass volumetrically, the following can be found:

1.2.1. Mass procedure

When the test to obtain the particle density of an aggregate is performed, after draining it and drying it with an absorbent cloth, sometimes a certain amount of surface water remains (from this point on referred to as *surface absorption*) and the aggregate contains some internal water absorption. Surface and internal water absorption vary fundamentally because they are dependent on time, the roughness of the aggregate and the interpretation of dry surface. These absorptions, obviously, have an effect on the mass of aggregates.

1.2.2. Volumetric procedure

Likewise, the randomness of the surface and internal water content according to the standard is responsible for the variability determining the volume of the aggregate, and that causes **underestimation** or **overestimation** of the particle density, as stated above.

As far as we know, referring always to dry particle density is reasonable because it is related to the mass of the aggregate completely dry. Dry particle density thus obtained would be the reference. When the water content or the water absorption is known, proper corrections will be carried out, as appropriate.

Moreover, according to the current standard, the absorption in an aqueous medium is defined as shown in Eq. (1).

$$W_{abs} = \frac{(M_{ssd} - M_d)}{M_d} \cdot 100 \tag{1}$$

where M_d is the mass of the dry state sample and M_{ssd} is the mass of the sample with a saturated surface-dry state.

When performing the test according to UNE EN 1097-6 for coarse aggregates, at least, three disadvantages were observed.

i) As was indicated in Eq. (1), value of M_{ssd} is obtained drying the surface of the aggregate, but this variable can be random due to sample handling. Water content can vary from some percentage points (less or more), due, among other things, to the fact that: water can be removed more or less from the open porosity during the drying surface process; the possible presence of water on the surface of the aggregates; the intensity and duration of drying; the cleanliness and moisture of the absorbent cloth, etc.
ii) The border between the aqueous absorption and eventual surface moisture is not well defined and both can be juxtaposed.
iii) The process requires a lot of repetitive handling which may increase the uncertainty of the result.

For particles between 4 and 0.063 mm, the method applied is the cone test according to the Annex F of the standard. The disadvantages described in the procedure with respect to the coarse fraction of the aggregate should be added to the fine fraction caused by air-drying [15]. This can cause the loss of the finer particles (air) and loss of the internal water (by hot air) without taking into account the ambiguity about the kind of water "absorbed" because it may or may not include traces of surface water, as was previously mentioned.

1.3. Objectives

In order to avoid the inaccuracies mentioned, a new methodology is proposed to determine both the density of the particles and the water absorption of the lightweight, normal-weight or heavy-weight aggregates. A continuous process is suggested in the methodology proposed, without handling randomness of the samples, and it allows us to find out about the evolution of the net or total water absorption of aggregates from the starting time (t_0) to the ending time (t_n), whatever it is, exempt from controversy and eventual presence of surface water.

2. New methodology for determining particle density

In order to reduce the disadvantages previously mentioned and avoid water content that could interfere in the aggregates (surface and internal water absorption), different materials were used to carry out the test, including "waterproof" external aggregates (zinc stearate and Vaseline) but conserving water as the test fluid. Others such as "hydrophobic" (sunflower oil and glycerol) were used as test fluids instead of water. After several trials with the materials mentioned, glycerol ($C_3H_8O_3$) was chosen for its higher density (1265 kg/m^3), viscosity (1.5 Pa s) and non-absorption by the aggregates and easy handling.

The duration of the test is approximately 10 min between the time the aggregate comes into contact with the glycerol and the final weighing with the pycnometer filled up to the calibration mark.

The procedure for determining the density of the particles with glycerol is summarized in Fig. 1. During the test, no significant absorption of glycerol is observed. Up to 15 min, a very slight absorption is noted, roughly 0.1% in normal and heavy-weight aggregates, and about 0.2% in lightweight aggregates. However, in intervals of longer duration, a slight and progressive increase in the absorption of the glycerol is observed. In 24 h absorption is around 4% for lightweight aggregates and 0.5% for normal and heavy-weight aggregates.

Since the slight increase in absorption starts at 15 min (5 min after the end of the test), we estimate that the use of glycerol can be accepted. Hence the absorption does not affect the test.

A new method to determine the particle density is proposed using glycerol as a test liquid, considering that glycerol does not penetrate in the aggregates. The mass of the aggregates is obtained absolutely in dry conditions superficially and internally. The new method allows for the obtaining of a dry particle density of the aggregate as **a fixed value of the sample tested**. Indeed, the particle density obtained with the standard is not useful; **it is not a fixed value of the tested material but rather a variable** thereof, depending on the water content, as was pointed out previously.

Following the new method, the real volume of the aggregate (V_{Md}) is obtained and consequently its dry mass (M_d). The procedure is good for all aggregates: lightweight, normal-weight and