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Water absorption measurement of fine porous aggregates using an evaporative method: Experimental results and physical analysis

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A B S T R A C T

Assessment of the so-called "saturated-surface-dried" state shows a strong dependency on the test operator in the case of fine porous aggregates. This leads to low reliability and reproducibility of water absorption measurement for this family of particles. Evaporative methods for water absorption measurements seem to be a promising alternative. In this paper, we aim at evaluating the robustness and the limit of such methods while understanding the general underlying physical processes. We therefore measure the drying kinetics of non-porous and porous, real and model particles with various sizes and morphologies. We study specifically the unexpected effects of angularity and roughness of particles on drying rate changes over time. Our results suggest that this method is not suitable for all porous particles but shall apply well to crushed fine porous particles such as crushed sand and recycled sand.

1. Introduction

Due to an increase in the use of both crushed and recycled aggregates, the average water absorption of the chemically inert particles used in the mix-design of cementitious materials is progressively increasing. As a consequence, both coarse aggregates and sands used nowadays show a greater tendency to absorb water from the fresh material through the entire mixing, transport and casting phases. It has therefore become a usual practice to compensate, during the mixing process, this water to be potentially absorbed.

This compensation is based on both a measurement of the initial water content of these aggregates and a preliminary independent assessment of their total water absorption ability. This latter assessment is usually carried out using the standard water absorption measurement method [1] established for rounded natural aggregates, which were dominating concrete mix design through the 20th century. In this method, sample is immersed in water for 24 h and then progressively dried to reach the so-called "saturated surface-dried" state, in which the porosity of the particles is filled with water while their surfaces are still dry.

Although this method can easily be transferred to coarse aggregates no matter their origins and/or shapes, it seems to generate difficulties and become strongly operator-dependent in the case of crushed or recycled sands or, more generally, any non-rounded non-natural fine porous particles.

For coarse centimetric particles (*i.e.* relatively low specific surface), the color change in the surface is a good indicator of the particle surface moisture state. For finer particles, however, this indicator becomes insufficient to provide a reliable assessment of the saturated surface-dried state. For sands, it is therefore supported by a slump measurement in the absence of fine colloidal particles (see Fig. 1). Dry rounded natural particles samples are expected to reach a conical shape with a cone slope between 15 and 30°. However, as soon as excess water is added to a saturated surface-dried sand, capillary menisci appear between sand grains. They decrease the slump of the sample and increase the slope of the sand deposit (see Fig. 1). This shift in behavior is obvious and allows the operator to precisely measure the amount of water needed to saturate the grains. In the case of crushed particles, however, the slump of the dried sample is initially quite low. The roughness of the particles, their irregular shapes and the associated inter-particle direct frictional contacts all increase the sand deposit ability to withstand gravity forces. Thus, the cone angle for dry samples can reach values higher than 45°. The formation of water menisci between sand grains does not affect much this equilibrium shape (see Fig. 1) and the shape of the sample stays the same over a large range of added water amounts. The assessment of the saturated surface dried state is therefore left to the operator decreasing the reliability and reproducibility of the measurement.

Within the above frame, evaporative methods for water absorption measurements seem to be a promising alternative as shown in [2]. The authors indeed observed an abrupt change in the drying kinetics of an initially water-saturated powder layer. They suggested that, in a first

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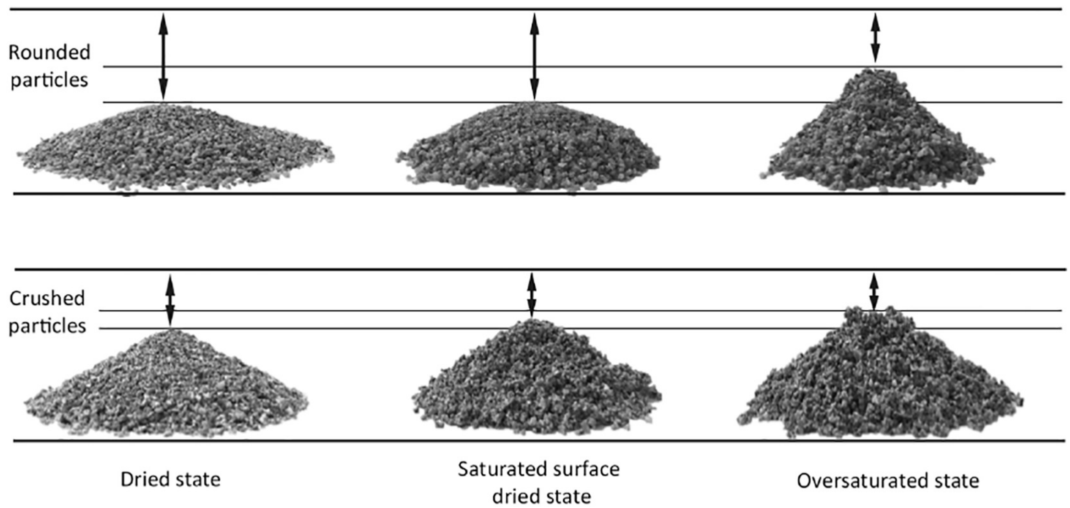

Fig. 1. Sand samples shapes for rounded particles (top) and crushed particles (bottom) for increasing amount of water (from left to right). The arrows indicate the slump of the tested material. The initial sample shape is a 15 cm-high truncated cone with lower diameter of 10 cm and upper diameter of 5 cm.

regime, the inter-particle water evaporates until, in a second regime, the only water left in the sample is the absorbed intra-particle water. In this second regime, a drastic drop in drying rate shall be measured. These authors claimed that such a transition could allow for the measurement of fine particles water absorption.

In this paper, we aim at evaluating the robustness and the limit of such a method while understanding the general underlying physical processes. We therefore measure the drying kinetics of non-porous and porous, real and model particles with various sizes and morphologies. We study specifically the unexpected effects of angularity and roughness of particles on drying rate changes over time. Our results suggest that this method is not suitable for all porous particles but shall apply well to crushed fine porous particles such as crushed sand and recycled sand.

2. Materials and protocols

2.1. Particles

We study here model glass beads and three types of sands. The glass beads diameters are 0.26 mm (from CVP *Abrasif & Broyage*), 1 mm, 5 mm and 7 mm (from Sigmund Lindner). We moreover study here one naturally rounded siliceous sand, one crushed limestone sand and one recycled concrete sand. The recycled sand was produced from the crushing and sieving of a concrete with water to cement ratio W/C = 0.84 and containing 230 kg cement. We only focus in this paper on sands and therefore on the 0/4 mm size classes (see Fig. 2). It can be noted from Fig. 2 that the particle size distributions of the three types of sands are substantially the same with a median diameter around 2 mm.

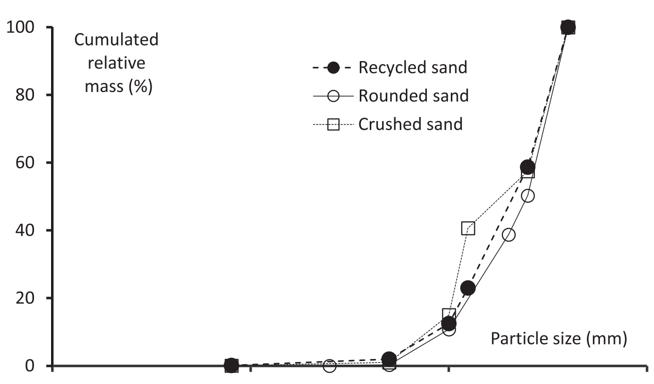

Fig. 2. Particle size distribution of the sands studied here.

Table 1
Physical properties of the sands studied in this paper.

	Rounded sand	Crushed sand	Recycled sand
Density (kg/m^3)	2.69	2.65	2.54
Water absorption – w_0 (%)	0.6	2.8	9.05
Dense packing fraction	62%	57%	57%
Roughness typical size (micrometers) – see text	150/200	200/250	200/250
Roughness volume fraction (%) – see text	1.6	4.2	3.9

Density and water absorption were measured according to the standard NF 1097-6 described in the introduction (see Table 1). The tests was carried out 3 times for rounded and crushed sands and 10 times for recycled sands by the same test operator with a relative error of 8, 10 and 7% respectively. We also report in Table 1 the random dense packing fraction of these sands measured in a container submitted to a 50 Hz vibration with 0.5 mm amplitude for 3 min [3]. A 200 g mass was applied above the sample as shown in Fig. 3.

We finally carried out some morphology measurements. For each sand, from numerical images with a pixel size of 21 μm of around 30

Figure 3. Random dense packing fraction measurement using external load and vibration [3].