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Water absorption in recycled sand: New experimental methods to estimate the water saturation degree and kinetic filling during mortar mixing

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HIGHLIGHTS

- Behavior of recycled sand in mortar mixing.
- A new vacuum-based method combined with an evaporation method to measure the WAC.
- A new experimental approach to follow the absorption kinetics of the RS.
- An adequately pre-saturating the RS can improve the mortar consistency.

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ABSTRACT

Use of recycled concrete aggregates (RCA) as construction and building materials has not yet spread out. One of the reasons lies in porosity: a given RCA is more porous than its natural aggregate because of the presence of the attached old cement paste. This higher porosity causes inadequate mixing due to increase in both RCA water absorption and water exchange between RCA and new cement paste. It is thus necessary to quantify the weight fraction of in-pore water, which is usually done through the so-called water absorption coefficient (WAC), and to decrease this potential water exchange by pre-saturating the RCA. This paper aims to investigate mortar mixes made of RCA that is 1–4 mm in diameter called recycled sand (RS). It puts forward a new vacuum-based method combined with an evaporation method to measure the WAC, which permits saturating the RS fully and confirming that the standard method (NF EN 1097-6) largely underestimates the WAC (as already pointed out by other works). The evaporation method is also used to measure the water content of the pre-saturated RS, in order to evaluate the proportion of the pores that remain accessible to water even after pre-saturation, which was not done in other works. This paper then puts forward a new experimental approach to follow the absorption kinetics of the RS by immersing them into a limestone filler, which allows better reproduction of mixing mortar since aggregates are added into cement paste and not into water. Last, it is shown that adequately pre-saturating the RS can improve the mortar consistency.

1. Introduction

The sustainability of primary resources is threatened by the construction industry because the amount of construction and demolition waste (CDW) produced and dumped into landfills is increasing each year [1]. This situation has forced the concrete industry to generate effective solutions such as implementing CDW as recycled concrete aggregates (RCA) to produce new types of concrete. Furthermore, a recent life cycle assessment study proved that the concrete made of RCA presents the best environmental behavior [2]. CDW is currently used in the road and sidewalks construction and maintenance. However, it needs further investigations before being used completely as RCA in new concrete for building construction field because of the poor porosity properties of the RCA.

RCA consists of 2 phases: natural aggregates and hardened cement paste (old binder). The latter is known to mainly cause RCA to be more porous than natural aggregates [3]. This high porosity generates an important water absorption coefficient (WAC) [4,5]. The WAC of the RCA increases with the increase of the amount of adherent cement paste [6]. Many studies [4–9] were

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conducted in order to determine the WAC of the RCA and they concluded that the WAC is underestimated by the standard method NF EN-1097-6. A higher value of WAC leads to a higher water exchange between RCA and the new cement paste. Indeed, this water exchange raises the problem of using a convenient W/C ratio to fabricate new RCA-based concrete with appropriate fresh and hardened properties.

With regard to the fresh properties, it was found in [10] that the incorporation of crushed clay bricks as a replacement for the natural aggregates reduces the W/C ratio and affects mortar flow. Similar result was found in [11]: the more the incorporation of brick waste, the more mixing water needed to obtain the adequate consistency of mortar. It was also found in [12] that a higher WAC of the RCA causes a decrease in both the yield stress and the plastic viscosity of the RCA-based mortar. For these reasons, it was advised in [13,14] to pre-soake the RCA or use the RCA in a dry state and then add the water needed for the absorption in the mix. Using the RCA in the dry state increases the initial slump [5,15–17]. This can be related to the high initial quantity of water used in the mix to compensate the high WAC. It was found in [18] that the pre-saturation of the RCA by soaking for 3 and 5 min enhanced the initial slump value of concrete and that the slump value increased with the soaking time interval. In [19], it was shown that the high WAC of fine recycled aggregates reduces the W/C ratio and reduces the mortar consistency. So it was proposed to add the recycled fine aggregates in the mixer with a determined quantity of water and to mix them for 5 min. After leaving the concrete mix for 10 min at rest, other components are added. This technique was found to improve the consistency of the concrete. A different working procedure was followed in [20] by pre-saturating recycled sands in a plastic bottle: it was found that the slump flow decreases with the increase of the pre-saturation time and pre-saturation water quantity. All this controversy implies the need to develop a better understanding of the water absorption kinetics of the RCA as well as the influence of the saturation state of the RCA in order to allow a better use of RCA in the construction and building field.

We here are aiming to contribute to RCA-based production of mortar and concrete. To do so, fine RCA is eliminated and only 1–4 mm fraction, called recycled sand (RS) is used. The reason is that smaller particles contain greater amount of attached mortar which alters the properties of the new concrete [6], such that many studies did not recommend the use of fine RCA in producing new concrete [21,22]. The main contributions of this paper are as follows:

- Determine a more accurate water absorption coefficient that is denoted here by Reference WAC (RWAC) by using a new method that combines a vacuum-based method and an evaporation method.
- Study the effect of the pre-saturation process on the empty pores of the RS by determining the water content after pre-saturation based on the previous evaporation method.
- Investigate the absorption kinetics of the RS in the mortar mix using limestone filler as model material.
- Study the influence of the saturation state of RS on the consistency of mortar.

2. Materials

CEM I 52.5 N CE CP2 NF is the type of cement used in this study; its chemical composition is given in Table 1. The limestone filler used in the absorption kinetics test is provided by Betocarb, its chemical composition is shown in Table 2. The recycled sand used in this study was provided by the French national project Recybeton as a fraction of 0–4 mm. The sand received (natural and recycled) is sieved between 1 and 4 mm before any use. Fig. 1 shows that the particle size distributions of both sands are similar. Knowing that RS has a heterogeneous structure and its properties depend on the source of supply, it is important to determine its characteristics prior to any use. Physical properties of the RS and the NS such as compactness, WAC and density are determined using the standard method NF EN 1097-6 [23]. The results are shown in Table 3. The RS has a higher WAC than the NS, the density and compactness of the RS are lower than the NS. This is expected since the RS is more porous than the NS. A total volume substitution of the NS by RS is proposed in this study.

3. Experimental program

3.1. Saturated surface dry (SSD) state measurement by evaporation

The SSD state is defined in [24] as 'the condition in which the permeable pores of the aggregate's particles are filled with water. This condition is achieved by submerging in water for the prescribed period of time, but without free water on the surface of the particles'. This quantity of absorbed water by the specimen is referred to as the water content of the specimen which is expressed as a percentage weight (mass of the water divided by the oven dry mass). The SSD state takes into account the absorbed water only whereas the wet state of RS consists of a film of water on the surface in addition to the absorbed water, as depicted in Fig. 2.

The most commonly used methods to determine the SSD state consist in toweling and drying the particles with a hot air flow. However these methods are considered subjective since the operator alone decides when the surface of the material is dry [25]. In addition, the toweling method is not recommended [26,27] because of a loss of material remaining attached to the towel.

To determine the quantity of water absorbed in RS, we here measure the weight variation of a wet sample under drying at constant temperature and relative humidity conditions. According to the theory of porous media [28,29], the free water and the absorbed water do not evaporate at the same rate. Evaporation includes three main phases beginning with a transition phase followed by a constant phase (evaporation of the free water) and then

Table 1
The chemical composition of the cement.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	S^-	Cl^-	CO_2	Free CaO	Ignition loss
20.2%	5.1%	3%	64%	1%	3.1%	0.75%	0.21%	0%	0.03%	0.4%	1.6%	0.7%

Table 2
The composition of the limestone filler used.

$CaCO_3$	Cl^-	SO_4^{2-}	S	Organic materials	Methylene blue test	Alkaline equivalents	SiO_2
98.80%	0.001%	0.001%	0.005%	0.01%	0.3 g/kg	0.005%	0.1%