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Durability-related performance of concrete containing fine recycled aggregates from crushed bricks and sanitary ware

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ABSTRACT

Information on the effects of incorporating fine recycled ceramic aggregates on concrete's durability is very scarce. This paper presents an experimental study using aggregates sourced from crushed red clay ceramic bricks (CBAs) and sanitary ware (SWA). Different concrete mixes were produced where the fine natural aggregate fraction was partially or fully replaced (20%, 50% and 100%, by volume) by each of these materials. Shrinkage, water absorption by immersion, water absorption by capillary action, carbonation and chloride ion penetration tests were carried out. Results show that using fine CBA provides better performance in terms of water absorption by capillarity and chloride ion penetration, contrarily to shrinkage, water absorption by immersion and carbonation penetration. Using fine SWA leads to a similar performance in terms of shrinkage, but all other properties are significantly and detrimentally affected. Notwithstanding the increased water requirement due to the high absorption capacity of CBA and the formation of agglomerated particles with SWA, this paper shows that a judicious use of these materials may allow the production of adequate structural concrete; in mixes with SWA the use of superplasticizers is a very effective approach in preventing the formation of clusters, even providing a better performance than the control concrete.

1. Introduction

Vast amounts of waste materials are produced by the construction and demolition industry every year [1]. The volume of these materials has reached an unacceptable level from an environmental, economic and social point of view. These issues may be addressed by means of more proactive approaches, which include recovery, reuse and recycling techniques and facilities.

It takes many years for a waste management system to grow into a sustainable, reliable, skilful and marketable industry, encouraging the reuse and recycling of components and materials. It is necessary that all parties involved (i.e. clients, contractors, planners and manufactures) play their role in achieving a more sustainable approach. This can be done by extending the life cycle of materials, components and resources. The use of recycled materials in high- rather than low-grade applications must also be a priority in the near future. In order to be successful in this approach, a correct choice of materials, recycling procedures and manufacturing processes is fundamental.

Since concrete is the most widely used construction material in the world, one way to promote sustainability in construction is by improving the environmental performance of this material. One of the most effective ways of doing so is by processing construction and demolition waste (CDW) and reintroducing them as recycled aggregates (RA) in new concrete.

The use of RA in concrete has been a target subject of study in recent decades, having created a sound scientific basis that demonstrates the feasibility of using them in structural concrete. Research on the performance of recycled aggregate concrete (RAC) mainly focused on the effect of introducing the coarse fraction of recycled concrete aggregates (RCA) on the mechanical performance of concrete [2], leaving out other types of RA also capable of producing concrete with adequate quality [3].

Recent investigations on the performance of concrete made with coarse [4–10] and fine [11–13] recycled ceramic aggregates or a combination thereof [14–16] have given positive results, which support and encourage further investigation on the incorporation of these materials in the production of concrete and their subsequent use in civil engineering structures. Khalaf [8] evaluated the effect of using 100% coarse recycled masonry aggregates (RMAs), from crushed brick units with varying strength, on the compressive strength of concrete. It was observed that RMA from high-strength brick units allowed the production of RAC with equivalent compressive strength to that of NAC. Regarding coarse RMA obtained from crushed red clay hollow bricks, de Brito et al. [5] reported an approximately linear reduction on the compressive strength of concrete with the incorporation level (24% strength reduction for 50% incorporation).

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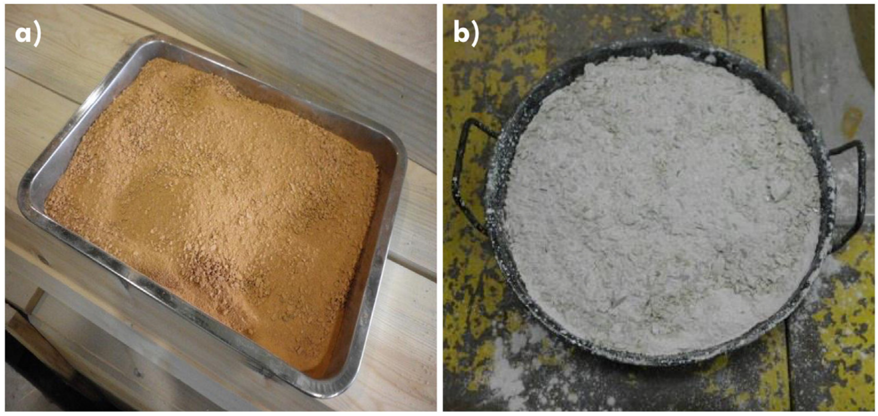

Fig. 1. (a) Recycled fine brick aggregates and (b) recycled fine sanitary ware aggregates (before being sieved).

Dhir and Paine [6] studied the effect of incorporating several blends of mixed recycled aggregates (MRA) with varying RCA and RMA content in the production of concrete. It was found that, for a given replacement level, as the coarse RMA content increased, so did the drying shrinkage. However, when Khatib [11] incorporated increasing amounts of either fine RCA or RMA, an opposite trend occurred. The results showed that the shrinkage of RAC made with 100% fine RCA was almost 60% greater than that of the control NAC, whilst it only showed a 10% increase for the same amount of fine RMA.

In terms of water absorption, the incorporation of increasing amounts of RMA usually produces specimens with increasing water absorption [4,7,12]. Because of this greater porosity, RAC mixes containing these materials tend to exhibit higher coefficients of accelerated carbonation and chloride ion migration coefficients. Gomes and de Brito [7] studied the influence of adding different RA types on the durability-related properties of RAC. They concluded that, when using 25% of coarse RMA, the carbonation depth and chloride ion migration coefficient increased by 30% and 19%, respectively. Similar findings were reported by Paine and Dhir [17].

Medina et al. [10] evaluated the influence on concrete behaviour of replacing (15% to 25%) natural coarse aggregate by RA produced by crushing ceramic sanitary ware. The concrete mixes were designed according to the La Peña method [18] (resulting in water/cement ratios ranging between 0.51 and 0.53 for the reference mix and that with 25% replacement, respectively). The performance of the different mixes was evaluated in terms of compressive and splitting tensile strengths. Both properties consistently increased with the replacement level. This study focused only on mechanical properties.

Halicka et al. [16] investigated the mechanical properties of concrete with alumina cement and full incorporation of fine and coarse RA obtained from crushed sanitary ware. In these experiments, the water content and the water/cement ratio were kept constant for the various mixes. As in the study of Medina et al. [10], RAC presented better mechanical performance compared to conventional concrete, in terms of compressive and (flexural) tensile strengths and abrasion resistance, but at the expense of (much) lower workability. This study also addressed the post-heating performance of RAC, which proved to be more stable than conventional concrete regarding residual mechanical properties. This study did not address the durability properties of RAC.

The literature review presented above shows that there is an obvious lack of information regarding the influence of the incorporation of fine recycled ceramic aggregates in terms of the durability behaviour of concrete, specifically in what concerns fine RA from crushed sanitary ware. Therefore, this study intends to assess the influence of incorporating these materials on the durability-related performance of concrete. An experimental programme was designed in order to investigate the effects of using these aggregates on drying shrinkage, water absorption by immersion and capillarity, carbonation and resistance to chloride ion penetration were investigated.

2. Experimental programme

2.1. Materials

Three coarse limestone natural aggregates (NA) of different grading size ranges were used in this research work: coarse gravel; fine gravel, and “rice grain”. Two fine quartzite NA of two size ranges were used (coarse and fine river sand). The fine NA fraction was replaced by RA sourced from crushed ceramic bricks (CB) and sanitary ware (SW), illustrated in Fig. 1. Each aggregate was sieved according to the sizes listed in EN 933-1 [19] and stored separately. These materials' size distribution was then defined according to the Faury size grading curve [20] in order to be the same in all concrete mixes. Cement type CEM II A-L 42.5 R, according to EN 197 [21], and tap water were used in all the concrete mixes.

Table 1
Mix proportion of the various concrete mixes.

Concrete mix	Cement (kg/m^3)	Water (kg/m^3)	w/c_{total}	w/c_{eff}	NA (kg/m^3)		RA (kg/m^3)	
					Coarse	Fine	CB	SW
CC	350	186	0.53	0.53	938	770	–	–
C20CB	350	196	0.56	0.53	938	616	118	–
C50CB	350	214	0.61	0.53	938	385	295	–
C100CB	350	224	0.64	0.53	938	–	591	–
C20SW	350	266	0.76	0.76	938	616	–	180
C50SW	350	273	0.78	0.78	938	385	–	450
C100SW	350	301	0.86	0.86	938	–	–	900

Table 2
Summary of experimental tests performed on fresh and hardened concrete.

State	Property	Test standard
Fresh state	Slump	EN 12350-2 [27]
	Fresh density	EN 12350-6 [28]
Hardened state	Compressive strength	EN 12390-3 [29]
	Drying shrinkage	LNEC E-398 [30]
	Water absorption by immersion	LNEC E-394 [31]
	Water absorption by capillarity	LNEC E-393 [32]
	Carbonation depth	LNEC E-391 [33]
	Chloride ion migration coefficients	NT Build 492 [34]