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Influence of pre-soaked recycled fine aggregate on the properties of masonry mortar

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HIGHLIGHTS

- The use of pre-soaked recycled fine aggregate (RFA) slightly reduced the consistency of masonry mortars.
- Pre-soaking increased the compressive strength of masonry mortar.
- Only mortars with pre-soaked RFA matched the compressive strength of the control mortar.
- Using RFA without increasing total water content gave greater compressive strength than natural aggregate mortars.

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ABSTRACT

The main aim of this study has been to determine the influence of pre-soaked recycled fine aggregate (RFA) on the properties of masonry mortar. A control mortar and six mortar series were prepared in which 25%, 50%, 75% and 100% natural aggregate (NA) was replaced with pre-soaked or non-pre-soaked RFA. Total water content of the recycled mortars was equal to or greater than that of the control mortar. The results show that pre-soaking slightly reduced the consistency of the mortar while improving bulk density (in both the fresh and hardened state) and air content, particularly with total NA substitution; compressive and flexural strength were increased with all RFA ratios. Therefore, the pre-soaking method of masonry mortar manufacture can help reduce the absorption capacity of these aggregates and improving recycling.

1. Introduction

The construction industry can help improve the environment by reusing and recycling construction and demolition waste (C&DW), which would in turn reduce both landfill volumes and consumption of raw materials [1–3]. In this regard, the use of recycled aggregate (RA) from C&DW in different building [4–7] and civil engineering [8–10] projects would make a major contribution to the sustainable development of the construction industry, even though the coarse fraction of the RA is usually used in these applications. Recycled fine aggregate (RFA) is composed of natural aggregate (NA) bonded with cement mortar, which reduces the density and increases the water absorption capacity with respect to NA [4,11–12]. These properties are detrimental to concrete and mortar quality because they directly affect the water/cement ratio (w/c), giving poor fresh state consistency and workability, and also affecting the mechanical performance in the hardened state [13]. As a result, most international regulations forbid the use of RFA in concrete [14]; however, there are no prohibitions on its use in mortar.

The workability of mortar is determined by its consistency, and must be suitable for each specific on-site application. A suitable workability is achieved when a plastic consistency is obtained with the addition of the required amount of water, thus enabling the binder paste to cover the surface of the aggregate [13]. When the RFA absorbs part of the mixing water consistency is impaired, and this in turn affects workability. Bektas et al. [15] used RFA as a replacement for NA in mortar at a constant w/c ratio, and this had a negative effect on the flow of the mortar. However, incorporating 30% RFA to their study mixture provided enough workability and good consolidation, depending on the proportions used in the mixture.

One way to reduce the absorption capacity of the RA is to increase the amount of mixing water [12,16–20]. Corinaldesi and Moriconi [16] and Jiménez et al. [18], for example, increased the

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volume of mixing water to achieve the required mortar consistency. Leite et al. [19] evaluated the compensation index of RA water absorption rates (60%, 70%, 80% and 90%) and concluded that in the case of recycled concrete an index of between 80% and 90% would be satisfactory for both workability and compressive strength. Several authors pre-soaked RA before use, keeping mixing water constant [21–24]. Barra de Oliveira and Vázquez [21] and Poon et al. [23] note the impaired strength of concretes made with saturated RA, concluding that at higher saturation levels the mechanical bonding between the cement paste and the RA is weakened, and that semi-saturated RA improved performance. Finally, Etxeberría et al. [24] used pre-soaked RA with 80% of total absorption capacity, obtaining an efficient interfacial transition zone (ITZ) between RA and new cement paste.

The presence of larger amounts of adhered cement mortar in RFA increases absorption with respect to coarse RA; pre-soaking, therefore, could improve the manufacture of mortars. Some authors reported using RFA in the manufacture of masonry mortars by increasing mixing water [12,16–18], however the use of pre-soaked RFA has not been studied in depth. Consequently, the main objective of this study was to analyse the influence of pre-soaked RFA on the behaviour of masonry mortars in the fresh and hardened state in order to manufacture strong mortars with sufficient plasticity to be used in construction.

2. Materials and methods

2.1. Materials

Mortar samples were manufactured according to the dosage recommendations for commercial masonry mortar provided by ARGOS D.C. The components used are described below:

- *Cement*. The cement used in this study was CEM II/A-L 42.5 R.
- *Additive*. A commercial air-entraining plasticizing admixture (RHEOMIX 932) was used to improve workability.
- *Filler*. A BETOCARB P1-DA limestone filler was added to the aggregate to adjust the fineness modulus.
- *Aggregate*. Two types of aggregate were used in this study: a dolomitic NA produced in a local quarry in Padul (Granada, Spain), and a RFA produced in a C&DW treatment and recovery plant located in Alhendín (Granada, Spain). RFA was obtained from RA from civil engineering concrete waste, the components of which, determined according to EN 933-11 [25], included: 87% concrete, 7.5% NA, 2.5% brick, 1.6% asphalt and 0.2% others impurities. Table 1 summarizes the physical, mechanical and chemical properties and standards used to determine the properties of the aggregate according to EN 13139 [26] specifications for mortar aggregates. Fig. 1 shows the particle size distribution of the aggregates, analysed in accordance with Standard EN 933-1 [27]. The Spanish National Association of Mortar Manufacturers (Asociación Nacional de Fabricantes de Morteros-AFAM-) recommends a larger amount of fines [13] (see ideal aggregate (IA) curve in Fig. 1), so it was necessary to add limestone filler to correct the fineness modulus of NA and RFA to nearer 2.23, resulting in the corrected curves in Fig. 1 used for this study.

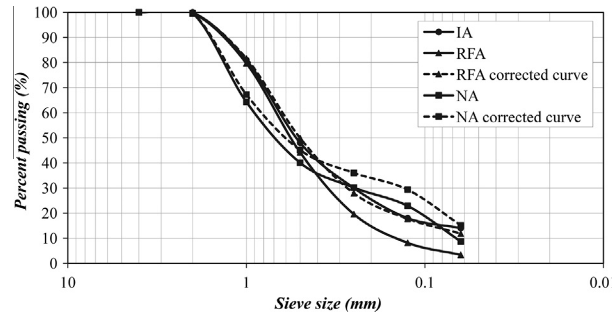

Fig. 1. Particle size distribution of aggregates.

2.2. Methods

2.2.1. RFA pre-soaking method

A pre-soaking method was used for RFA, and consisted in mixing it with water before adding it to the other dry components of the mortar (natural aggregate, cement and additive). The pre-soaking water and the RFA were mixed in the mixer at a slow speed for 5 min. Subsequently, the pre-soaked RFA was left to rest for 10 min.

Four pre-soaking methods were used, one based on the literature consulted and the other three proposed specifically for this study, varying the amount of pre-soaking water used with the RFA. The methods used are described below (Table 2):

- *PS-100 Method*. The RFA was pre-soaked in a volume of water equivalent to its full absorption capacity (WA_{24h}).
- *PS-80 Method*. Proposed by Etxeberría et al. [24], the RFA was pre-soaked in 80% of its WA_{24h}.
- *PS-92 Method*. The RFA was pre-soaked in 92% of its WA_{24h}; this was the water absorbed during a 10-min period (WA_{10min}) (Table 1), which according to other authors [5,20] is the volume of water absorbed by the RFA during mixing.
- *PS-67 Method*. Pre-soaking water was 2/3 of the total absorption capacity of RFA, corresponding to 67% of WA_{24h}.

2.2.2. Mortar samples

Six masonry mortar series with various substitution ratios (25%, 50%, 75% and 100%) of NA by RFA by mass and a control mortar to be used as a reference were manufactured for this study (Table 3). Mortar samples were assigned the name of the series and the RFA content ratio. Mortar components were dosed by weight according to the manufacturer's directions to obtain a dry mass of 3 kg for a type M-5 compressive strength mortar according to EN 998-2 [32] (Table 4). The same mixing procedure, according to EN 1015-2 [33], was used to manufacture all the mortar series. This included the following steps: (i) solid components (including pre-soaked RFA according to the process described in Section 2.2.1 above) were mixed to obtain a dry homogeneous mixture; (ii) mixing water was poured into the mixer container; (iii) solid components were added to the water and (iv) all components were mixed for 90 s at low speed.

Three groups of series were manufactured according to the literature (A0, B0, C0), differing in the amount of mixing water, total water and RFA moisture (non-pre-soaked or pre-soaked RFA). Some of the foregoing methods were modified to identify new test conditions, resulting in series A1, C1 and C2. For all mortar series, the total water was pre-soaking water plus mixing water, while the effective w/c

Table 1
Properties of NA and RFA.

Property	Standard	Limit value	NA	RFA
Aggregate size	EN 933-1 [27]	No limit	0/2	0/2
Fines content (%)	EN 933-1 [27]	⩽30	8.71	3.36
Fineness modulus	EN 13.139 [26]		2.43	2.49
Sand equivalent (%)	EN 933-8 [28]	No limit	71	99
Dry sample density (g/cm^3)	EN 1097-6 [29]	No limit	2.82	2.63
Water absorption (WA_{24h}) (%)	EN 1097-6 [29]	No limit	1.3	6.3
(WA_{10min}) (%)				5.8
Water-soluble chlorides (%)	EN 1744-1 [30]	⩽0.06	0.003	0.014
Acid soluble chlorides (%)	EN 1744-5 [31]	No limit		0.009
Acid soluble sulphates (%)	EN 1744-1 [30]	⩽0.8	0.3	0.58
Total sulphur (%)	EN 1744-1 [30]	⩽1	⩽1	0.66
Humus content (%)	EN 1744-1 [30]	No limit	Exempt	Exempt
Light organic impurities (%)	EN 1744-1 [30]	No limit	Exempt	Exempt