Construction and Building Materials 145 (2017) 303–310

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of recycled aggregate on physical-mechanical properties and durability of vibro-compacted dry-mixed concrete hollow blocks

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HIGHLIGHTS

- Geometric, physical-mechanical and durability of recycled concrete blocks have been studied.
- Blocks made with total replacement of concrete recycled aggregate showed the best results.
- Partially replacement of mixed recycled aggregates showed the best total absorption.
- Recycled aggregate led to the incorporation of the precast industry into the circular economy.

ARTICLE INFO

Article history:
Received 7 December 2016
Received in revised form 21 March 2017
Accepted 4 April 2017

Keywords:
Construction and demolition waste
Recycled aggregate
Technological nutrient
Precast blocks

ABSTRACT

This paper deals with the feasibility of using fine and coarse recycled aggregates, both from concrete and mixed sources, as technological nutrients for the production of vibro-compacted dry-mixed concrete hollow blocks traditionally used in wall construction. Five series of blocks were prepared with different combinations of concrete and recycled aggregates and a reference one to be used as a control series. The results shows that the incorporation of recycled aggregates does not compromise compliance with the European standard EN 771-3, nor further durability requirements by means of hazardous ambient such as freeze-thawing and salts crystallization and the value declared by the manufacturer.

1. Introduction

According to Eurostat [1], in 2010 the total generation of waste from economic activities and households in the EU-28 amounted to 2506 million tonnes and, despite the downturn in economic activity, construction activity accounted for the largest share of generated waste with 860 million tonnes (34.32%). With respect to treatment, almost half of these 2339 million tonnes treated was subject to disposal operations other than incineration, predominantly in landfills. Construction and demolition waste was traditionally disposed in landfills, supposing a great management problem for governments since, besides, it significantly affects the environmental degradation.

Construction and demolition waste (C&DW) mainly comes from building and infrastructure demolitions, which fundamentally include concrete, masonry mortar and ceramic materials, thus they are not dangerous since they are considered inert according to Council Decision 2003/33/EC [2]. They, however, generate environmental problems not only derived from the high volume produced, but also from its treatment and disposal in dumps [3]. Accordingly, they should be properly treated in industrial treatment plants for the production of recycled aggregate and used as conventional aggregate, helping to preserve the environment by reducing the expenses related to construction and demolition waste management, and to protect the natural resources [4].

In recent years numerous studies have been published regarding the use of recycled aggregate (RA) in structural concrete [5–7], non-structural concrete [8,9], mortars [10–12], and road construction [13,14]. Most of them affirmed that the quality of RA is lower than that of natural aggregate (NA), being the higher absorption, the adhered mortar and the impurities that limit their use.

Abbreviations: CHB, concrete hollow blocks; EU-28, 28 member states of the European Union; C&DW, construction and demolition waste; RA, recycled aggregate; NA, natural aggregate; CRA, concrete recycled aggregate; MRA, mixed recycled aggregate.

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http://dx.doi.org/10.1016/j.conbuildmat.2017.04.013
0950-0618/

Notwithstanding, technical regulations allow the use of RA except for fine RA [15] where such shortcomings are more sharply manifested.

Nonetheless, RA has been infrequently used in low-value-added applications as non-structural precast concrete where there are no restrictions of RA use or at least these are not so limiting. Poon and his colleagues have focused part of their investigations on this option [16–19]. They found that it is possible to produce concrete paving blocks for pedestrian areas and for traffic with different partial combinations of recycled aggregates, even using the fine fraction of RA despite the mechanical strength reduction [19]. According to Poon and Chan [18], an allowable contamination level can be increased from 1% to a maximum of 10% in the production of paving blocks. In this regard, practically all of the studies found were about solid concrete precast pieces such as blocks [3,20–25], paving blocks [26–28], or pavement flags [27,29]. These studies have demonstrated that it is feasible to incorporate up to 100% of coarse and fine RA for the production of non-structural concrete pieces; however, higher cement quantities have to be used for this type of precast in order to maintain the mechanical requirements.

Nevertheless, only a few authors have studied the behaviour of recycled precast concrete hollow elements using RA. Dominguez and his colleagues [30] produced hollows bricks obtaining not too favorable results. In the experiment of López Gayarre [31], the physical properties of the floor blocks obtained were not overly affected, in accordance with the standards; this was not the case, however, of their mechanical behaviour, which resulted significantly dwindled. Recently, Rodríguez et al. [32] experienced a linear loss of flexural strength of hollow tiles manufactured with coarse MRA; they concluded that the essential properties of hollow tiles are retained until a 25% of MRA substitution is reached. Finally, Matar and El Dalati [4] concluded that using RA without NA in the manufacture of concrete hollow blocks is not economical due to the necessity of a high rate of cement addition in order to obtain the required compressive strength.

Therefore, the aim of this study was focused on the production of non-structural dry-mixed concrete hollow blocks (CHB) with the incorporation of coarse and fine RA which complied with the requirements of the European standard EN 771-3. *Specification for masonry units. Part 3: Aggregate concrete masonry units (Dense and lightweight aggregates)* [33], and, in addition, which were capable of manifesting an adequate durability against certain extreme ambient conditions such as freeze-thaw and salt crystallization. In this regard, and since recycled aggregates from C&DW can be considered as technical nutrients in the circular economy, their use in the manufacture of low-graded applications becomes a guarantee of fulfilment of the objectives established in the Directive 2008/98/CE [34] requiring that 70% of C&DW generated should be reused, recycled and assessed in 2020.

2. Materials and methods

2.1. Materials

CHB were fabricated according to the dosage recommendations of the manufacturer for these commercial blocks. The components used to make the forecast dry-mixed concrete blocks are outlined below:

– Portland cement EN 197-1 CEM I 42.5 R [35], commonly used in precast concrete manufacture.
– Admixture FRIOPLAST P by SIKA. It is a water-reducing and plasticizing admixture designated to achieve the adequate compaction and demoulding of dry concretes made with extruder machines. This admixture was used to improve cohesion and compactness since a small quantity of water is needed in this kind of pieces because workability is not as important as in conventional concretes.
– Dolomitic NA from a quarry in Padul (Granada-Spain), and concrete recycled aggregate (CRA) and mixed recycled aggregate (MRA) from a C&DW treatment and recovery plant in Granada (Spain). The aggregates in size 0/5 and 5/8 mm were mixed in a proportion of 64% and 36% in weight respectively. The process at the C&DW plant consists of a simple impact crushing, and separation with vibrating screens. Metallic elements are removed by using a magnetic conveyor belt and large impurities, such as plastics, paper, glass, and gypsum are extracted by hand before the crushing process. According to the guidelines established in the European standard EN 933-11 [36], CRA fell into the category of concrete recycled aggregate due to major content in concrete and unbound aggregates (88.34%); on the other hand, MRA was classified as mixed recycled aggregate due to the significant presence of ceramic particles (Table 1). Finally, Spanish Structural Concrete Code EHE-08 [15] and the project of European standard EN 12620 [37] have been considered to establish the specifications for aggregates (Table 1); according to them CRA drew continuous curves (Fig. 1) and fulfilled the requirement regarding density and content in chlorides, nevertheless MRA presented a content in sulphates somewhat higher than the specified one (Table 2).

2.2. Dosages

Six boards with 7.5 pieces of 400 × 200 × 200 mm were elaborated with each aggregate combination, according to the manufacturer recommendation. The samples have been named according to the reference dosage and the substitution rate of NA by RA used, as shown in Table 3. Additionally, each series has been designated in compliance with EN 771-3 [33], indicating the number and date of publication of the European Standard, the type of piece, dimensions and manufacturing tolerances, and compressive strength. Table 4 shows the reference dosage: 7.5% of cement EN 197-1 CEM I 42.5 R, water/cement ratio of 0.61, 0.5% admixture FRIOPLAST P from SIKA, for each series.

Considering that RA is considerably more absorbent than NA (see Table 2), in order to limit the absorption of the mixing water and, therefore, the water demand of recycled concrete [18], generally researches take into account the pre-soaking of RA before being added to the mixer. Samples fabrication process has considered recommendations such as pre-soaking the RA during 10 min before its use with the 80% of the water corresponding to its absorption. In this regard, since dry-mixed concrete was manufactured, pre-soaked water did not interfered in the increase of the

Table 1
Classification of the constituents of coarse recycled aggregates according to EN 933-11 [36] and category specified according to EN 12620 [37].

Sample	Constituent	Content (%)	Category
CRA	Rc	80.00	Rc80
	Rc + Ru	88.34	Rcu70
	Rb	11.66	Rb30-
	FL	0.00	FL0.2-
MRA	Rc	63.01	Rc50
	Rc + Ru	68.01	Rcu50
	Rb	31.85	Rb50-
	FL	0.14	FL0.2-

Rc, concrete, concrete products, mortar, concrete masonry units.
Ru, unbound aggregate, natural stone, hydraulically bound aggregate.
Rb, masonry units (i.e. bricks and tiles), calcium silicate masonry units, aerated non-floating concrete.
FL, floating materials.