Construction and Building Materials 149 (2017) 507–514

Contents lists available at ScienceDirect

Construction and Building Materials

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

Influence of recycled brick aggregates on properties of structural concrete for manufacturing precast prestressed beams

Jesús Suárez González [a], Fernando López Gayarre [a,*], Carlos López-Colina Pérez [a], Pedro Serna Ros [b], Miguel A. Serrano López [a]

[a] Polytechnic School of Engineering, University of Oviedo, Viesques Campus, 33203 Gijón, Spain
[b] ICITECH, Polytechnic University of Valencia, Vera Campus, 46022 Valencia, Spain

HIGHLIGHTS

- Structural concrete has been manufactured using recycled brick aggregates.
- Coarse and fine natural aggregates have been replaced by recycled brick aggregates.
- Percentages of substitution have been 20%, 35%, 50%, 70% and 100%.
- The elastic modulus decreases noticeably when recycled aggregates are used.
- Precast pre-stressed joists can be manufactured using recycled aggregates up to 35%.

ARTICLE INFO

Article history:
Received 9 February 2017
Received in revised form 13 May 2017
Accepted 17 May 2017

Keywords:
Recycled brick aggregates
Fine fraction replacement
Coarse fraction replacement
Precast concrete

ABSTRACT

The European Union has set as a target for 2020 the reuse of 70% of non-hazardous construction and demolition waste (C&DW) in order to reduce its impact on the environment and on health, as well as to improve the efficiency of available resources.

Within the framework of this initiative, this study addresses the use of ceramic aggregates from precast production facilities in order to replace natural aggregates for manufacturing structural concrete for the production of precast prestressed beams. The objective of this study is to evaluate the influence of the substitution of the fine and coarse fraction of natural aggregates for ceramic brick aggregates in the mechanical properties of concrete, with the aim of applying the results obtained to the subsequent manufacture and testing of prestressed beams commonly used in one-way slabs.

The focus of this analysis is on the replacement of the fine fraction of the natural aggregate by the recycled one. However, the coarse aggregate was also substituted. Furthermore, two hardly studied replacement percentages (35% and 70%) were included in the experimental program. The main result obtained was that prestressed beams can be manufactured with up to 35% of the proposed type of ceramic recycled aggregates in order to reach the requirements of the European standards.

1. Introduction

Construction and demolition waste (C&DW) is the largest type of waste in the European Community in terms of amount generated. Specifically, the construction sector generated 871 million tons in 2014, equivalent to 33.5% of the total waste generated [1].

Current EU policies aim to reduce the impact of this waste on the environment and on health as well as to improve the efficiency of available resources. The long-term goal is to turn Europe into a recycling society, reusing waste whenever possible and minimizing the extraction of natural resources. The efficient use of resources will be a key factor to advance in the fight against climate change. It will allow the protection of environments of great ecological value and, eventually, it will improve the quality of life of current and future generations. Furthermore, from the economic point of view, the recycling of C&DW is considered a cost-effective alternative since, in many cases, the cost of waste disposal is high due to the taxes of landfills and/or transport costs compared to the costs of sorting, reusing and recycling. For all these reasons, the European Union has set the objective of reusing 70% of non-hazardous C&DW by 2020 [2]. Following this path, national [3–5] and international [6] regulations have been published which contain indications for the recycling of C&DW.

* Corresponding author.
E-mail address: gayarre@uniovi.es (F.L. Gayarre).

http://dx.doi.org/10.1016/j.conbuildmat.2017.05.147
0950-0618/

Concrete waste and ceramic materials are the most abundant components within C&DW and its use as aggregates in the manufacture of concrete has been the subject of numerous studies to date, most of them regarding recycled concrete aggregates (RCA) and, to a lesser extent, recycled brick aggregates (RBA).

RBA can be classified into two categories depending on their origin. Firstly, the porous ceramic materials, such as fired clay, which have undergone vitrification during the firing process (bricks, roof tiles, etc.). They have low hardness and high water absorption (12–18%). Secondly, the waterproof and semipermeable materials that have undergone vitrification (ceramic stoneware, ceramic tiles, etc.), with high hardness and low water absorption (5–7%). These differences will have a clear influence on the properties of the concrete made with them.

The present study focuses on the RBA from rejected pieces in ceramic precast facilities. This material is characterized in the European List of Waste (ELW) [7] as "10.12.08 Ceramic, brick, roof tile and construction materials waste (fired)". It is a very homogeneous waste, free from unwanted materials such as poor quality mortar or even plaster. In addition, it is available in large amounts since it represents between 3% and 7% of the overall production of the ceramic industry [8].

With a focus on this type of waste, several authors have carried out studies aimed at assessing the consequences of partially or totally replacing the fine, coarse, or both, of the natural aggregates by RBA, especially in middle and low strength concrete and, to a lesser extent, in structural concrete.

De Brito et al. [9] found that, for non-structural concrete (<25 MPa), the replacement of coarse fraction of natural aggregates by this type of aggregates generates a linear loss of strength in concrete that reaches 45% for a percentage of substitution of 100%. A similar result has been obtained by Zeng and Wan [10].

On the other hand, in a study published by Debieb and Kenai [11], when both fine and coarse fractions are replaced by RBA in middle strength concretes (<40 MPa), it is noted that the loss of resistance reaches 40% for a 100% replacement percentage. This author also states that this loss is reduced to 30% when only the fine fraction is substituted.

Cachim [12] finds, for middle-strength concretes (<45 MPa), that with up to 50% replacement of the intermediate fraction, with RBA, there is no loss of strength and, for a 100% substitution the decrease does not reach 20%.

The results are better for RBA with low water absorption. Torkittikul and Chaipanich [13] state that the compressive strength of concrete made from this type of ceramic aggregates is greater than the one with natural aggregates for percentages of substitution of fine fraction up to 50%. An even better result has been obtained by Pacheco and Jalali [8]: using ceramic sand of low coefficient of water absorption (6%), they have concluded that replacement of natural sand by ceramic sand is a good choice because resulting concrete presents no loss of strength and has longer durability.

Some authors state that there is a difference in the behavior of RCA and RBA fines. In this sense, Khatib [14] observes a reduction of up to 30% of the resistance when using fine RCA but, however, when using RBA fine aggregates, he does not appreciate a reduction of resistance until 50% of substitution. Even for a 100% replacement, the reduction is only 10%. Along these lines, Cabral [15] concludes that concrete produced with recycled aggregates presents a loss of strength except for RBA fines, where even a slight increase in resistance is observed.

Some studies have also been carried out to evaluate the use of RBA in manufacturing high strength concrete (HPC) (>70 MPa) by incorporating additives into its composition in order to achieve high values of compressive strength. In this line, González Corominas and Etxeberría [16] concluded that, from the mechanical and durability point of view, high strength concrete can be produced with up to 30% RBA fine aggregates, with equal or better characteristics than the conventional one. On the other hand, Suzuki et al. [17] concluded that up to 40% substitution of the coarse fraction, incorporating additives, leads to a significant increase in the compressive strength due to the effect of internal curing produced by this type of aggregate.

Avoiding the use of additives, Alves et al. [18] have carried out a study in which it was concluded that structural concrete of good quality and middle strength (<45 MPa) can be produced with RBA fines, with a loss of strength lower than 10% for a 50% replacement by recycled aggregates.

Although, in most cases, the results with recycled aggregates are not as good as those obtained with natural aggregates, current trends indicate that their recycling will be regulated in the mid-term. For this reason, the construction sector must study in detail the use of this waste to produce concrete, complying in any case, with the requirements imposed by the related regulations. Therefore, assuming that there will be a reduction in the quality of the concrete, it is necessary to assess how far this reduction takes place and to ascertain the extent to which recycled aggregates can be incorporated for each specific application.

Following this path and in view of the results obtained in previous articles, the present piece of research addresses the use of RBA from precast plants, replacing natural aggregates (both fine and coarse fraction) for the manufacture of structural concrete (>45 MPa). Using additives was avoided and the concrete is intended to a very specific application, which is the production of precast prestressed concrete beams.

This study was carried out together with a local company of precast concrete products in which the prestressed beams were manufactured with the intention of assessing the possibility of recycling the ceramic waste that is generated in a plant of precast ceramic components located in the vicinity.

The first step of this study was to evaluate the influence of the substitution of natural aggregates by RBA on the mechanical properties of concrete which is used routinely by the cooperating company for the manufacture of precast beams. Then, depending on the results obtained and using the most suitable proportions of RBA, the beams will be manufactured and tested.

The present report corresponds to the first phase previously exposed. According to standard EN 15037-1 which regulates the production of precast concrete products [19], the concrete to manufacture prestressed beams must be of normal density (between 2000 and 2600 kg/m^3 according to EN 206-1 [20]) and a minimum class C30/37 according to the same standard. Although this is the minimum value required by the standards, the concrete used by the partner company to manufacture the beams has a compressive strength close to 60 MPa. For that reason, the objective is to assess how far RBA can natural aggregates be replaced to ensure that the strength of the resulting concrete does not deviate too far from this value (preferably >45 MPa).

Although compressive strength is a decisive factor in determining the suitability of a concrete, other important characteristics such as tensile strength and modulus of elasticity will be evaluated in this study in order to verify if they agree with the expected values depending on the compressive strength.

2. Experimental study

2.1. Materials

Cement CEM I 52.5 N was used. It is commonly employed by the precast plant for the manufacturing of prestressed joists. Its main characteristics are summarized in Table 1.