Construction and Building Materials 153 (2017) 364–373

Contents lists available at ScienceDirect

Construction and Building Materials

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

Physico-mechanical properties of multi-recycled self-compacting concrete prepared with precast concrete rejects

Ángel Salesa [a,*], Jose Ángel Pérez-Benedicto [a], Luis Mariano Esteban [b], Rosa Vicente-Vas [a], Martín Orna-Carmona [a]

[a] Materials and Structures Department, Engineering School of La Almunia, Universidad de Zaragoza, Spain
[b] Applied Mathematics Department, Engineering School of La Almunia, Universidad de Zaragoza, Spain

HIGHLIGHTS

- Structural use of recycled aggregate from precast concrete rejects.
- Investigate different properties of multi-recycled self-compacting concrete.
- Fresh and hardened concrete properties of three generations of 100% recycled concrete have been studied.
- Total replacement of coarse aggregate does not have adverse consequences on compressive strength performance.

ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form 4 July 2017
Accepted 9 July 2017

Keywords:
Recycled concrete
Multi-recycled concrete
Recycled concrete aggregates
Precast concrete industry
Self-compacting concrete

ABSTRACT

The precast concrete industry produces a substantial quantity of waste due to quality non-conformances. Rather than deposit them in landfill, these products can be crushed, generating recycled aggregate, a by-product that may be reintroduced in the manufacturing process. But, what would happen if the recycled concrete pieces were rejected again? Is it possible to recycle the recycle concrete? The purpose of this paper is to study the possibility of multi-recycling precast concrete, in one of its most popular precast industry types: self-compacting concrete. In this study three recycled cycles were carried out, all of them using 100% recycled aggregate.

The results showed that the new concretes with recycled and multi-recycled coarse aggregates from precast concrete rejects performed equally well, even slightly higher in compressive strength compared with control concrete; the increases at 28 days were 7.7%, 10.9% and 13.8% for the first, second and third recycling cycle, respectively. The performances of recycled concretes were better than reported in previous research, which is owing to the high quality of precast concrete recycled aggregates.

The precast concrete industry can be more eco-friendly with its new self-compacting concrete products, produced with aggregates recycled from quality test failure or old pieces after their service phase. With this, the precast concrete industry will close the recycling concrete circle, decreasing its environmental impact and incurring potential cost savings.

1. Introduction

Nowadays, world population growth and rising quality of life have led to increased construction activity. Consequently, this entails certain environmental costs. At present all the industrial sectors, including the construction industry, are trying to reduce their environment impact. In the building sector the possibilities are numerous.

One of them, which has been the focus of notable attention is to reuse construction and demolition waste (CDW) [1]. The magnitude of the problem is considerable, with 850 million tons of waste [2] generated in EU each year. This amount of CDW is used legally as filling material, but in some cases illegally dumped in landfill [3]. Although some countries such as Denmark and Germany achieve reuse ratios over 80% [4], other European countries have rates under 10% [5], so the problem remains.

The reuse of CDW has its maximum potential in the fabrication of new concrete, through the generation of recycled aggregate (RA) from the crushing and screening process of the CDW. Not only does this solution lead to a reduction of material deposited in landfills,

* Corresponding author at: Materials and Structures Department, Engineering School of La Almunia, Universidad de Zaragoza, C/ Mayor s/n, La Almunia de Doña Godina 50100 Zaragoza, Spain.

E-mail address: asalebor@yahoo.es (Á. Salesa).

http://dx.doi.org/10.1016/j.conbuildmat.2017.07.087

but it also entails a reduction in the amount of new aggregates extracted from quarries. In addition, it will cause a reduction in the amount of emissions of CO_2, thereby reducing the ecological footprint of construction sector [3].

Sometimes it is difficult to find non-mixed recycled aggregates, the quality of these usually being lower than the quality of natural aggregate. Therefore, certain recycled aggregates cannot be used in structural concrete and are assigned for making non-structural concrete [6] or for other purposes [7,8].

In recycled aggregate, obtained exclusively from concrete, there is a complete absence of materials with other origins; moreover, it can verify the parent concrete. To achieve this goal the solution is to perform a laborious process of selection and screening of CDW. However, the precast concrete industry can speed up the process.

In the precast concrete industry many precast elements are rejected for not passing quality controls (quality non-conformity), or it can also be the case that precast constructions have completed their service life. In both cases it is possible to obtain the traceability of the concrete elements, since the recycled aggregates are exclusively formed from concrete, usually of good quality.

In addition to the above mentioned, one of the most widely used types of concrete in the precast concrete industry is self-compacting concrete (SCC). This type of concrete was first developed in 1988 in Japan [9] with the purpose of achieving durable concrete structures, high deformability and not requiring external compaction or vibration. To produce SCC it is necessary to use aggregates, filler and admixture with special characteristics and high-quality.

It is now when one has to ask what will happen when recycled precast pieces finish their operational phase, or what will happen with the recycled precast pieces that are rejected a second or third time in the quality test. And the question which arises is this: Can we recycle recycled concrete?

The fundamental goal of this research is to study the possibility of multi-recycling (in the precast concrete industry) a special concrete type such as self-compacting is. Three generations of self-compacting recycled concrete (SCRC) were carried out, all of them with a 100% substitution of the natural coarse fraction by recycled coarse aggregate. A wide range of properties were analyzed for them in both phases: fresh and hardened, and compared with a control self-compacting concrete made just with natural aggregates.

Concrete recycling is an issue extensively studied in recent years, but few projects have focused on self-compacting recycled concrete [10,11]. There exists barely any research into concrete multi-recycled [12–15]. Due to the above, multi-recycled self-compacting concrete is a field that has not been adequately researched yet; accordingly it is precisely here where the essential purpose of the present research resides.

The results of this study demonstrate the viability of using recycled aggregates with higher substitution ratios than those permitted in the national construction regulations [16,17]. Moreover, the outcomes show the possibility of concrete multi-recycling and also prove the possibility of making non-conventional recycled concrete, like recycled self-compacting. All of this is possible due to the quality of parent concretes and thereby, of precast concrete aggregates.

2. Literature review

The present state of the question of recycled concrete has been researched by several authors. Most investigations have been focused on the use of coarse fraction because the use of fine fraction cause more problems or worse performance as has been reported in several research publications [3,18–20].

The main difference between the use of recycled aggregates (RA), from precast concrete rejects, and the use of natural aggregates (NA) is the presence of attached mortar and cement paste in RA, in contrast to NA [21].

As a general rule the substitution of NA by RA in concrete mixes entails a weaker performance, both mechanical and durable [1,22]. An important point is the effect of the quality of parent concrete on the properties of the RA and, consequently in the new concrete. In this connection, Kou S and Poon C [23] noted that RA derived from 80 and 100 MPa parent concrete can be used to replace up to 100% NA for the production of high performance concrete. Their viewpoint has been confirmed by other authors [24,25]. This is particularly important since the RA from the precast industry is generally just concrete recycled aggregate without other materials, and often with a parent concrete with strength over 30 MPa.

In addition, with the above the recycled coarse aggregates (RCA) substitutions have consequences on the workability of recycled concrete. It has been shown that for the same water content the workability is lower [26,27]. The consistency increase occurs and the water/cement effective ratio decreases due to the high water absorption capacity of mortar attached [28]. Notwithstanding, in order to improve the workability several procedures have been developed. The first option it is adding more water, so that it will be absorbed by the RA [21]; the second option is pre-soaking the RA [29], although it is hard to do so in industrial processes. The final option is to increase the quantity of plasticizers and superplasticizers in the mix [30,31].

Regarding the compressive strength of recycled concrete (RC), there are different results. In most of the research the strength is negatively influenced by the use of RCA [10,31,32]. Other studies show that strength is greatly influenced by the degree of substitution and the quality of the RCA [10,33,34]. Also important is the dependence of the water/cement ratio in the concrete strength, the differences between NC and RC being emphasised in recycled mixes with a low water/cement ratio [35,36].

In addition, other investigations show that when the level of RCA substituted is up to 20–40% of the total of coarse aggregates, the properties of concrete are not influenced by the presence of recycled aggregates, the concrete having a similar behaviour to conventional concrete [35,37,38]. Accordingly some codes stipulate a level of between 20% and 40% for the maximum replacement of coarse aggregate by RCA [16,17].

A negative point of RC, where consensus can be reached, is in its deformability properties. The modulus of elasticity is significantly influenced, showing a linear relationship with the percentage of RCA added [1]. The modulus of elasticity decreases with each recycled cycle due to the lower rigidity of recycled aggregates (caused by increasing presence of adhered mortar) [13,15].

Regarding the physical properties of RC, the density is lower than concrete made with NA [39], which is due to the adhered mortar present in the recycled aggregate [21,32]. This thinning can imply benefit when we are looking for a lightweight concrete. In addition, water absorption of RC increases due to the higher water absorption of recycled aggregates compared to natural aggregates [39]. This tendency is confirmed with each recycled cycle [15].

Finally, in relation to SCRC, studies point out that the usage of recycled aggregate for making self-compacting concrete impairs the properties of the concrete, especially the flow [40] and strength [41]. However provided there is an appropriate choice of material and design of the mixture, the use of RCA is justified [10].

3. Materials and experimental details

3.1. Materials

3.1.1. Cement

A CEM I 52.5R cement by "CEMEX Morata de Jalon", complying with the UNE EN 197-1 (2011) [42] code requirements, was used. This cement achieves a high strength in a short period and it is highly recommended in works or manufacturing