Construction and Building Materials 137 (2017) 128–140

Contents lists available at ScienceDirect

Construction and Building Materials

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

An experimental study on the relation between input variables and output quality of a new concrete recycling process

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HIGHLIGHTS

- Experimental studies were carried out with the aim of fine tuning a novel concrete recycling process.
- A novel experimental set-up was built to simulate autogenous milling.
- The influence of type of parent concrete, intensity of the autogenous milling and ADR cut-size point were investigated.
- Mechanical and durability properties of RAC is comparable to those of NAC.
- Special properties of recycled aggregates will make it a favorite input material for prefab industry.

ARTICLE INFO

Article history:
Received 1 August 2016
Received in revised form 23 December 2016
Accepted 25 January 2017

Keywords:
Concrete recycling
Recycled aggregate
Prefab concrete
Innovative technology

ABSTRACT

Enormous amount of Construction and Demolition Waste (CDW) are yearly generated in Europe and the predominant material constituent is concrete. Despite the urgency of creating a sustainable solution for End Of Life (EOL) concrete waste treatment, there has not been a large driving force for recycling it into prime grade materials. The C2CA concrete recycling process aims at a cost effective system approach to recycle EOL concrete to hardened cement and clean aggregates. This recycling process consists of a combination of smart demolition, gentle grinding of the crushed concrete in an autogenous mill, and a novel dry classification technology called Advanced Dry Recovery (ADR) to remove the fines. The main factors in the C2CA process which may influence the properties of Recycled Aggregates (RA) or Recycled Aggregate Concrete (RAC) include the type of Parent Concrete (PC), the intensity of autogenous milling (changing the amount of shear and compression inside of a mill) and the ADR cut-size point (usage of +2 mm or +4 mm RA in the new concrete). This study aims to investigate the influence of implied factors on the quality of the RA and RAC. To conduct the study, first of all, three types of concrete which are mostly demanded in the Dutch market were cast as PC and their fresh and hardened properties were tested. After nearly one year curing, PC samples were recycled independently varying the type of PC and intensity of the autogenous milling. Experimental variables resulted in the production of eight types of RA. The physical, mechanical and durability properties of the produced RA were tested and the effect of the experimental variables on their properties were investigated. According to the results, the type of PC is a prevailing parameter for the final properties of RA, in comparison with the milling intensity. Moreover, it is observed that a variation in the milling intensity mostly influences the properties of RA produced from a lower strength PC. Furthermore, the performance of the RA in the new concrete was studied. Four types of RAC were produced based on the modified recipe of their corresponding PCs. For the modification of the recipes, water absorption and density of RA were taken into account while the amount of applied cement and consistency class was kept similar to the corresponding PC. Experimental results show that the RAC samples compare favourably with PC. Among various autogenous milling intensities, milling at medium shear and compression delivers better properties for RA and RAC. Good performance of RAC with the incorporation of 2–4 mm ADR fines and RA, confirms the possibility of setting ADR cut-size point on 2 mm.

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http://dx.doi.org/10.1016/j.conbuildmat.2017.01.085
0950-0618/

1. Introduction

In the coming years, a strong increase of the amount of Construction and Demolition Waste (CDW) is expected in Europe because of the large number of structures from the 1950s which are coming close to their end of life [1]. End Of Life (EOL) concrete is known to be the heaviest component of the CDW. Considering the fact that public and private sectors have become aware of the urgency and importance of CDW recycling, the European Commission has taken initiatives towards sustainable treatment and recycling of CDW. In this regards, a novel concrete-to-concrete recycling process, (C2CA) is developed within European projects. The C2CA process aims at a sustainable and cost-effective system approach for recycling high-volume EOL concrete streams into prime-grade aggregates and cement [2].

The technologies considered are smart demolition to produce crushed concrete with low levels of contaminants, followed by mechanical upgrading of the material on-site into an aggregate product with sensor-based on-line quality assurance and a cement-paste concentrate that can be processed into a low-CO_2 input material for new cement. In C2CA process, after crushing and sorting out big contaminants, liberation of the cement paste is promoted by several minutes of grinding in an autogenous mill while producing as little as possible new fine silica. A new low-cost classification technology, called Advanced Dry Recovery (ADR) is then applied to remove the fines and light contaminants with an adjustable cut-point of between 1 and 4 mm for mineral particles [3]. ADR uses kinetic energy to break the bonds that are formed by moisture and fine particles and is able to classify materials almost independent of their moisture content. After breaking up the material into a jet, the fine particles are separated from the coarse particles. The finer fraction of crushed EOL concrete is problematic due to the moist mixture of silica aggregates, cement paste and water (10–15%), contaminated with 0.5–1% of foreign materials such as wood, metal and plastics.

The feasibility of the C2CA concrete recycling process was examined in a demonstration project involving 20,000 tons of EOL concrete from two office towers in Groningen, the Netherlands and delivered very promising results [1]. Fine tuning of this process, requires a comprehensive understanding of the effects of various influencing parameters on the quality of the produced aggregates. In C2CA process, the main factors which affect the final properties of RA and RAC include the type of PC, the setting of ADR cut-size and the intensity of autogenous milling.

In spite of the availability of considerable research aimed at a better understanding of the properties of RA and their influence on the performance of RAC, there are limited studies focusing on the effects of the involved recycling parameters in relation with the quality of final products [5–8]. Some research included the effect of parent concrete on the properties of the recycled aggregate concrete. According to Akbarnezhad et al. the PC properties such as strength and size of Natural Aggregates (NA) can strongly affect the properties of RA [8]. Kou et al. reported that RA derived from PC with high strength (80–100 Mpa) can be used to replace 100% with NA [7]. Other researchers claimed that for the same particle size, aggregates coming from weaker PC have greater dry density and less attached mortar which would result in a better quality concrete [8]. Similar to that, Padmini et al. reported that RA produced from PC with higher strength have higher amount of water absorption [5]. They also reported that for a given target strength, with increasing the strength of parent concrete, the strength of RAC reduces. However, Tavakoli et al. reported that if the compressive strength of the parent concrete is higher than that of the reference concrete, then the recycled aggregate concrete can also be made to have higher compressive strength than the control concrete [6]. They also expressed that higher water absorption capacity of RA, which partly reflects the increased amount of mortar adhered to original stone, lead to reduced compressive strength of RAC.

In addition to above mentioned research, few efforts were found which aimed at increasing the quality of RAC through the production processes [2,6,8,9]. It is reported that the liberation of cement from surface of aggregates will improve by using an autogenous mill [9,10]. However, the effect of autogenous milling intensity and its importance for recycling of different types of concrete is not yet well understood.

Furthermore, the effect of ADR cut-size on the performance RAC needs to be investigated. ADR is equipped with an adjustable cut-size point by which the minimum particle size of the recycled aggregates can be set on 2 mm or 4 mm. In fact, setting ADR cut-size on 2 mm means that the fraction 2–4 mm will be also incorporated for RAC production. Considering the fact that the fraction 0–4 mm (fines), is a massive by product of the concrete recycling process, it would be beneficial to use them partially in the RAC production. Evagelista et al. did a comprehensive review on existing reports related to the utilization of recycled fines in new concrete [11]. From their review they concluded that although the use of fines in concrete production is currently considered unacceptable by a major part of scientific community, some published results prove that if the problem is approached correctly, it is possible to make concrete containing recycled fines that affords high performance. However, due to large variation in the results of different researches, it deserves more investigation.

The aim of current study is to enrich the knowledge with respect to the fine setting of C2CA process to deliver RA and RAC with high quality and salability potential. The present paper reports on the findings of an experimental study on the influence of the above explained parameters "the type of PC, milling intensity and ADR cut-size point" on the performance of RA or RAC.

2. Materials and methods

2.1. Parent concrete

Three series of commonly used concrete in the Dutch market were chosen for casting as the Parent Concretes (PCs). To produce the specimens, ready mix concrete with real applications (see Table 1) and provided by Mebin in the Netherlands, were used. The mix proportions for considered types of PC are presented in Table 2. PCs consists of CEM III B 42,5 NLH and aggregates at three different grading with maximum sizes of 16 mm (for PC3) and 31,5 mm (for PC1 and PC2) (see Fig. 1). PC1 and PC3 contain just NA, while PC2 consists of 10 wt.% of 16–32 mm RA in addition to NA due to the actual industrial usage of RA in the Netherlands. All specimens were cast in molds and compacted using vibrators (see Fig. 2). Samples were demolded after 24 h in a controlled laboratory environment and were cured in the standard condition according to the EN-12390-2. Fresh and hardened properties of the parent concretes were determined (see Table 3) and the rest of the specimens were remained into the curing room with the standard condition (temperature 23 ± 2 °C and relative humidity of 95%) for a duration of one year. For each type of PC about100 cubes of concrete (15 cm × 15 cm × 15 cm) were casted.

2.2. Concrete recycling procedure

After almost one year curing, PCs were used as the input of the recycling process. Based on an experimental plan (explained in Section 2.3) different types PC samples were recycled separately. For recycling, a lab-scale version of C2CA process was applied.