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Performance of recycled aggregate concrete based on a new concrete recycling technology

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HIGHLIGHTS

- A new route for concrete recycling within the European C2CA project is developed.
- This novel recycling technology can be performed purely mechanically and in situ.
- The process applies ADR to extract high-grade recycled aggregate.
- We used ADR recycled aggregates for production of RAC.
- Results show minor impact of RA on the performance of RAC.

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ABSTRACT

One of the main environmental challenges in the construction industry is a strong social force to decrease the bulk transport of the building materials in urban environments. Considering this fact, applying more in-situ recycling technologies for Construction and Demolition Waste (CDW) is an urgent need. The European C2CA project develops a novel concrete recycling technology that can be performed purely mechanically and in situ. The technology consists of a combination of smart demolition, gentle grinding of the crushed concrete in an autogenous mill, and a novel dry classification technology called ADR to remove the fines. The feasibility of this recycling process was examined in demonstration projects involving in total 20,000 tons of End of Life (EOL) concrete from two office towers in Groningen, The Netherlands. This paper concentrates on the second demonstration project of C2CA, where EOL concrete was recycled on an industrial site. After recycling, the properties of the produced Recycled Aggregate (RA) were investigated, and results are presented. An experimental study was carried out on mechanical and durability properties of produced Recycled Aggregate Concrete (RAC) compared to those of the Natural Aggregate Concrete (NAC). The aim was to understand the importance of RA substitution, w/c ratio and type of cement to the properties of RAC. In this regard, two series of reference concrete with strength classes of C25/30 and C45/55 were produced using natural coarse aggregates (rounded and crushed) and natural sand. The RAC series were created by replacing parts of the natural aggregate, resulting in series of concrete with 0%, 20%, 50% and 100% of RA. Results show that the concrete mix design and type of cement have a decisive effect on the properties of RAC. On the other hand, the substitution of RA even at a high percentage replacement level has minor and manageable impact on the performance of RAC. This result is a good indication towards the feasibility of using RA in structural concrete by modifying the mix design and using a proper type of cement.

1. Introduction

Construction and Demolition Waste (CDW) is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 25–30% of all waste produced in the EU and consists of numerous materials, including concrete, bricks,

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gypsum, etc. which can be recycled [1]. According to the revised Waste Framework Directive, the minimum recycling percentage of 'non-hazardous' CDW, should be at least 70% by weight until 2020, while the current average recycling rate of CDW for EU-27 is only 47% [2]. In the coming years, a substantial increase in the amount of waste is expected in Europe because of the high number of constructions from the 1950s that are close to their end of life. At the same time, the demand for road foundation materials, an important outlet for the stony fraction of C&DW, is expected to decline with time, due to a reduction in the net growth of infrastructure [3].

By recycling part of the concrete fraction of C&DW into high-quality construction materials like aggregate and cement for new concrete, it is possible to take advantage of the surplus of waste. There has been vast research to solve associated problems with End of Life (EOL) concrete [4–8]. However, it should be noticed that due to the low price of concrete also the overall cost of the recycling process, the implemented concrete recycling route should be economically beneficial and environmentally sustainable.

A new technology of concrete recycling called C2CA (Concrete to Cement and Aggregate) aims at a cost-effective system approach for recycling high-volume EOL concrete streams into prime-grade aggregates and cement (see Fig. 1) [3].

The technologies considered are selective demolition to produce crushed concrete with low level of contaminants, followed by mechanical upgrading of the material on-site into an aggregate product with sensor-based on-line quality assurance and fines that can be processed (off-site) into Ca-rich material for new clinker production. In situ recycling of the aggregate is one of the primary goals of the C2CA. To achieve this, the process is performed purely mechanically and in a moist state, i.e. without prior drying or wet screening. This way reduces process complexity and avoids problems with dust or sludge. In C2CA, after crushing of EOL concrete, autogenous milling is used to remove the loose mortar from the surface of the aggregates. The removal of the loose mortar is mentioned to be one of the key points to improve the mechanical strength of the RA [4]. After autogenous milling, a new low-cost classification technology, called Advanced Dry Recovery (ADR) is applied to remove the fines and light contaminants with an adjustable cut-point of between 1 and 4 mm for mineral particles. ADR is a key technology in C2CA. It uses kinetic energy to break the bonds that are formed by moisture and fine particles and can 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. ADR separation has the effect that the aggregate is concentrated into a coarse aggregate product and a fine fraction that includes the cement paste and contaminants such as wood, plastics and foams [9,10]. Fig. 2 schematically shows the ADR principle.

In order to reduce cost and allow to ship the produced recycled aggregate to a concrete production company immediately, the C2CA project develops two types of sensors for automatic online quality control and quality assurance. The concept is to avoid the need for laboratory analysis and intermediate storage, minimize transport of bulk materials and combine, if possible, quality and end-of-waste certification at the site, without human intervention. A second major goal of the project, next to in situ processing and local reuse of the aggregate, is to help decrease CO_2-emissions in cement production by concentrating part of the cement paste from EOL concrete into a separate fraction that can be reused as a low-CO_2 feedstock replacing primary limestone. Already in 2000, world cement production amounted to 8.6% of global CO_2-emissions from fossil fuels [11].

The present paper accounts for the report on the re-use of recycled coarse aggregate produced via C2CA process. In spite of the availability of considerable research in this field [12–18], most of the existing information is not comparable due to the heterogeneity of the recycled aggregates, applied concrete mix designs and production. This paper includes all information regarding the concrete recycling process, properties of Recycled Aggregate (RA), and mechanical and durability properties of concrete using different RA substitution rates and different w/c ratios.

2. Materials and methods

2.1. Concrete recycling process

The concrete recycling was performed based on the C2CA process. Technologies that are smart dismantling and demolition, crushing, autogenous milling, and ADR processing were applied respectively [3]. EOL concrete originated from two governmental towers that were used as case study for the C2CA project. For this trial, a mill (5.6 m length, 2.2 m diameter and 12 rpm speed) with a maximum internal capacity of 16 tons was installed on site. Milling of materials was carried out followed by screening at 16 mm and an ADR with a maximum capacity of 120 tons per hour. Fig. 3 shows the concrete recycling process. It shows that ADR at the end delivers two main products: Coarse (4–16 mm) and fines (0–4 mm). In this study, ADR coarse product was used for the concrete production.

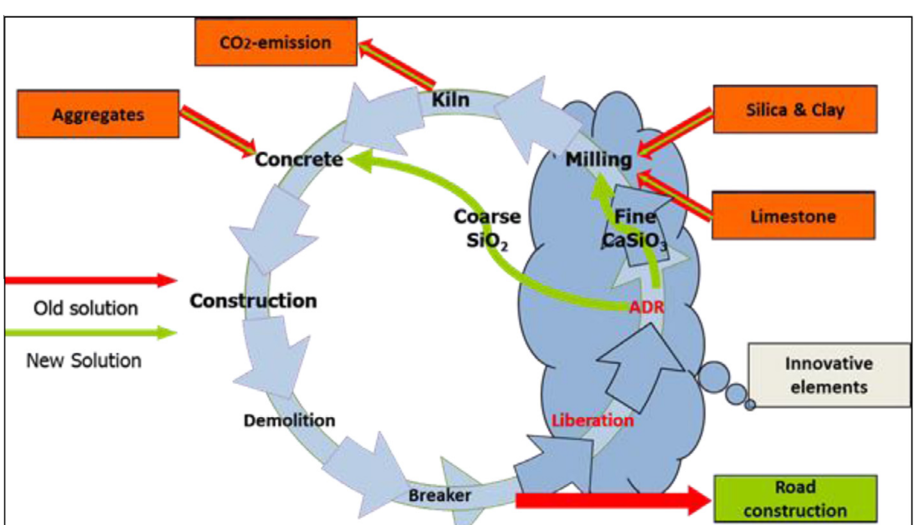

Fig. 1. C2CA in brief.