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Closing the loop of EOL concrete

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Abstract

Production of waste materials, via industrial and human activities, creates big environmental and economic problems but also opportunities to recover valuable resources. EU28 currently generates 461 million tons per year of ever more complex Construction and Demolition Waste (CDW) with average recycling rates of around 46%. There is still a significant loss of potential valuable minerals, metals and organic materials all over Europe. 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 funding three tandem projects focusing on the development of an innovative and sustainable concrete recycling process. To that end, this article will firstly present the main achievements and ongoing activities for developing the innovative concrete recycling technology in the course of the EU C2CA, HISER and VEEP projects. In addition some figures related to the cost of each recycling unit process and the selling price of the recycled products are presented.

Keywords: Concrete recycling- Recycled aggregates-Recycled concrete fines- Recycled cement.

Introduction

About 1,300 million tonnes of waste are generated in Europe each year, of which about 40%, or 540 million tonnes, is CDW. It is estimated that 60-70% of CDW belongs to waste concrete (about 320-380 Mt). A comparison between the figures related to the production of waste and new concrete, indicates that at present the rate of new concrete production is much higher than that for the waste concrete production. The reason is the large time-lag between the construction and demolition of a building which results in shifting the production of waste concrete to the future. Following the second World war II, a post-war economic boom (especially in western European countries) happened which resulted in a significant boost in the construction of buildings and infrastructures. Taking the mentioned time-lag into account, the amount of waste concrete is going to rise dramatically in the near future. Based on the revised Waste Framework Directive (WFD), the minimum recycling percentage of ‘non-hazardous’ CDW, should be at least 70% by weight by 2020. The current average recycling rate of CDW for EU-27 is only 47% and there is still a significant loss of potentially valuable materials all over Europe. This indicates that currently the market for recycled concrete may not be large enough and it needs innovations to create more attractive products.

Presently, the treatment of construction and demolition waste in Europe is mostly based on scenarios 1 and 2 which are indicated in Figure .1

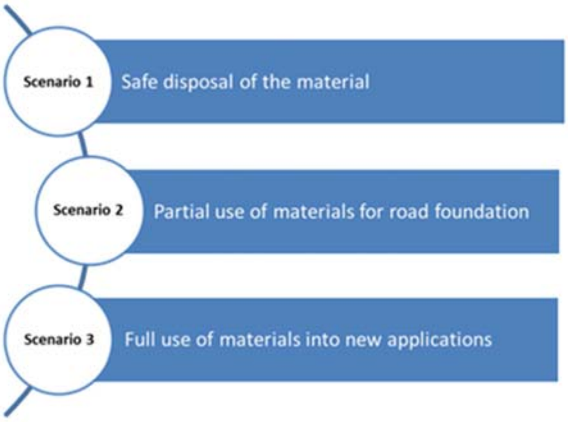
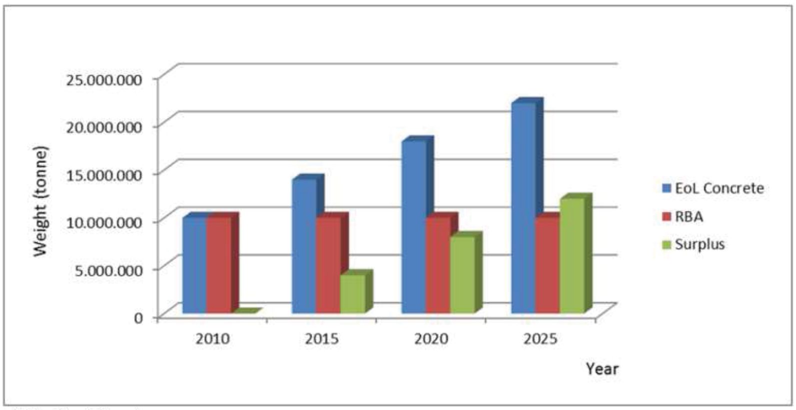


Figure 1. Three different scenarios for treatment of construction and demolition waste.

Following Scenario 1, some European countries allow the waste to be land-filled at very low gate fees. However, countries like the Netherlands encourage extensive material re-use through a strategy of selective demolition followed by recycling. With such a strategy, 85% of the material from End Of Life (EOL) building constructions is recovered as relatively pure mono-material fractions, and only 15% ends up as mixed demolition waste that has to be treated in specialized waste treatment facilities. The main mono-material fractions resulting from selective demolition are mineral, steel and wood. They have a neutral to positive value and are ideally suited for re-use at a high level. In particular, the large mineral fraction (85% of all CDW) is crushed off-site or on-site using mobile breakers and is typically applied as a substitute for natural gravel in road foundation (second scenario).

However, despite the fact that road foundation is a useful outlet for recycled aggregates, it is not a sustainable application in the long run. In the coming years, a strong increase of the amount of waste is expected in Europe due to the large number of constructions from the 1950s that are closing to their end of life. At the same time, the demand for road foundation materials is expected to decline with the time due to the reduction in the net growth of infrastructure. Government statistics of the Netherlands, for example, predict that whereas nearly 100% of the EOL concrete is absorbed by the Dutch road sector today, this number will have dropped to below 40% by 2025 (see Figure 2).



*RBA: Road Base Aggregates

Figure 2. Study of the Dutch government for the end of life concrete demand.

On the other hand, the required technology and business model for fully recycling and re-using of EOL concrete into new concrete is yet beyond what can be achieved by the recycling industry (Scenario 3 in Figure 1 is not mature yet).
In order to achieve a sustainable solution for recycling of concrete into new concrete the following goals should be reached:

1. To widely replace primary raw building materials through recycling of end of life concrete.
2. To achieve a substantial reduction in road transport of building materials.
3. To create a serious cut in CO_2 emission from cement production.

A wide, efficient and quick replacement of primary raw building materials by recycled materials besides a significant reduction in road transport and creating a considerable cut in CO_2 emission requires innovation of business model and technology which has been the focus of the three EU projects C2CA, HISER and VEEP.

Developments of the concrete recycling technology during the C2CA project

The C2CA project aimed at a cost-effective system approach for recycling high-volume EOL concrete streams into prime-grade aggregates and cement (see Figure 3). 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 (off-site) into a low-CO_2 input material for new cement. To achieve in situ recycling of the aggregate has been one of the main goals of the C2CA project. Therefore, liberation of fines rich of the cement paste, as well as the sorting and size classification of the aggregate, is performed purely mechanically and in the moist state, i.e. without prior drying or wet screening. After crushing and sorting out big contaminants, liberation of fragile parts from the surface of aggregates is promoted by several minutes of grinding in a small-diameter (D = 2.2m) 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 (See Figure 4). 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. ADR separation has the effect that the aggregate is concentrated into a coarse aggregate product and a fine fraction including the cement paste and contaminants such as wood, plastics and foams (see Figure 5). General layout of this innovative concrete recycling technology can be seen in Figure 6.

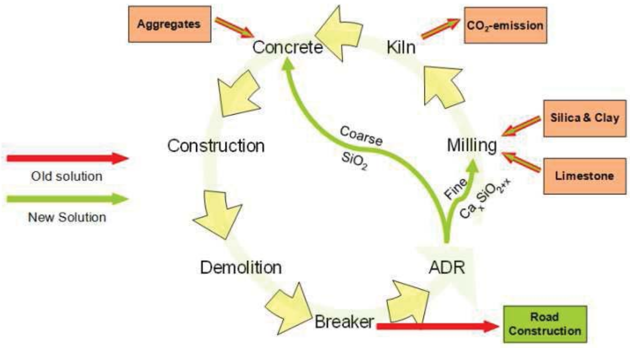


Figure 3. Existing vs. proposed novel closed cycle for concrete recycling.

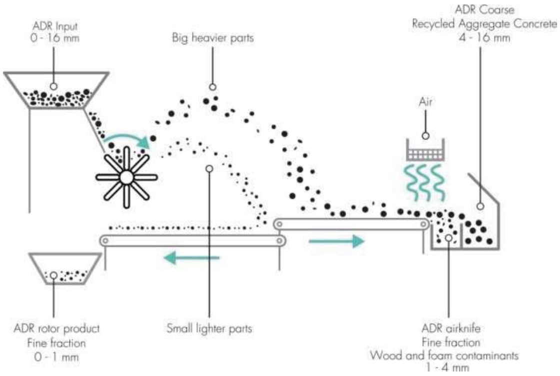


Figure 4. Schematic of the ADR principle

Figure 5. Products from crushed concrete by ADR: Coarse (left) and Fine (right).

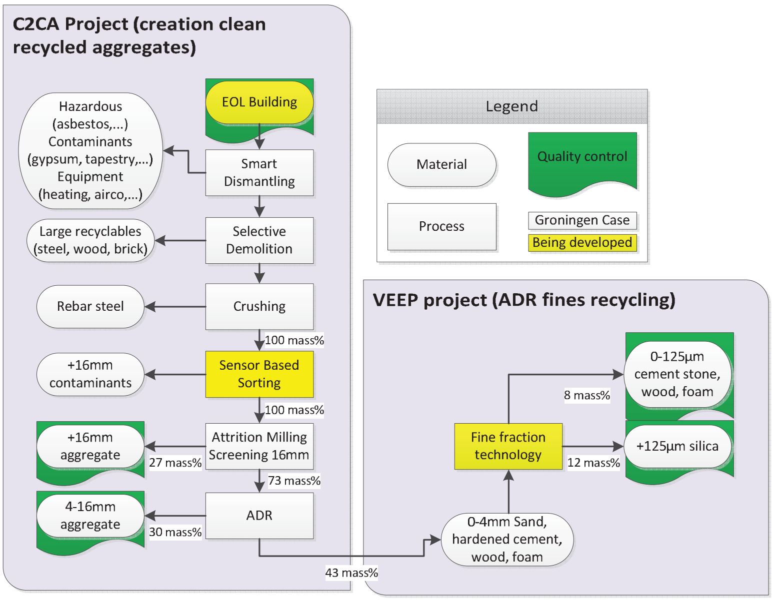


Figure 6. General layout of the C2CA technology showing the mass flow distribution for the concrete fraction. Some steps of the mechanical process are developed and fine- tuned during the C2CA project. The fine fraction technology part is being developed within the VEEP project.

During the C2CA project, The feasibility of this recycling process to produce clean recycled coarse aggregates was examined in a demonstration project involving 20,000 tons of EOL concrete from two office towers in Groningen, the Netherlands. Results show that the recycled aggregate compares favorably with natural aggregate in terms of workability and the compressive strength of the new concrete, showing 30% higher strength after 7 days and after aging this difference has become lower, to 5% at 90 days (See Figure 7).

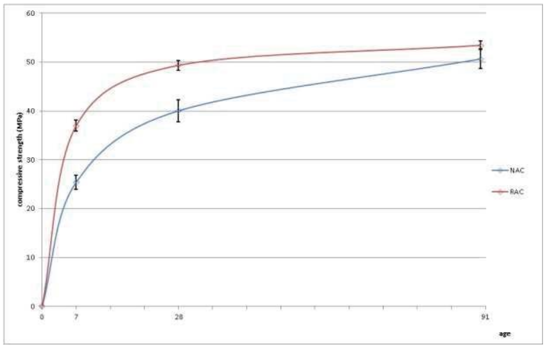


Figure 7: Comparison between compressive strength of NAC and RAC in different ages.

Developments of the concrete recycling technology during the HISER project

HISER project in general is developing and demonstrating novel cost-effective technological and non-technological holistic solutions for a higher recovery of raw materials from C&DW. The main components of C&DW are being investigated with the aim to valorize and to use them as replacement of virgin raw materials. In so doing an effective switch from linear to circular economy is achieved.

As the follow-up of the C2CA project, during HISER, industrial ADR insulation was demonstrated in the city of Hoorn in the Netherlands in June 2016. This successful demonstration was the result of a detailed design and built engineering (See Figure 8) for upscaling of ADR followed by the onsite performance evaluation. The recovery of each size fraction into all three up-scaled ADR products and the cut-points is shown in Figure 9. According to the results the share of coarse, rotor and airknife products are about 56.5wt%, 31wt% and 12.4wt% respectively. Currently Hoorn site is active producing clean recycled aggregates >4mm for the pre-fab and ready mix concrete production companies in the Netherlands.

Figure 8: ADR upscaling (Join activity of TUDelft and GBN Group-Strukton Civiel, C2CA Technology)- Hoorn- the Netherlands

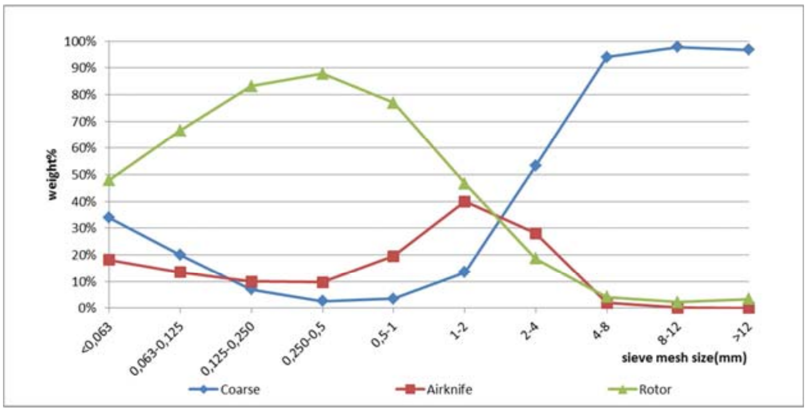


Figure 9. The recovery percentage of each size fraction into the three products of ADR.

The C2CA and HISER projects have mainly developed, fine-tuned and demonstrated an innovative concrete recycling technology to produce coarse recycled aggregates. However, there is still a need to recycle the created crushed concrete fines. ADR Fines (AF) contains hardened cement, unliberated pieces of sand, moisture and light contaminants such as wood. In fact, the main problem with crushed concrete fines is associated with its contaminated and moisturized nature that also applies for AF. The wet state of AF makes any dry separation process like screening or ball milling inefficient and costly while the contaminated nature of AF is the main concern for re-using it into new concrete. To deal with these problems, at the end of C2CA and during HISER, some proofs of concept at TRL3 were performed to develop a combination of simultaneous heating, grinding and separation process to produce two main products from ADR fines: clean, dry sand ready for using in the concrete production and a concentration of cementitious powder with a very low amount of contaminants ready to sell as a minerals resource to the cement production companies. The research set-up consisted of a Heating-Air classification System (HAS) followed by grinding of materials using a Ball Mill (BM). Experimental results show that heating of the materials to 500^0C for a duration of 30 seconds, results in a significantly reduced milling time. This is important for the milling cost and to avoid the production of new fine silica during the grinding. When comparing different heating temperatures in terms of the efficiency, recovery of hardened cement, sand and contaminants removal, 500°C is concluded as the most suitable temperature. The fraction 0-0.125 mm always shows the highest percentage of the CaO and consequently hardened cement. The amount of CaO in the produced very fine fraction is comparable with the amount of CaO in low-quality limestone (see Table 1)

Table 1. XRF values for ADR fines and FF in comparison to limestone and clay component

Oxides	ADR fines directly used in C2CA trial	FF (0-0.125 mm) resulted from heating and grinding	Example Clay	65% $CaCO_3$ (marl) Limestone-low quality	95% $CaCO_3$ Limestone-high quality
SiO_2	75.49	41.2	67.30	21.80	2.83
Al_2O_3	4.57	6.42	9.00	5.48	0.69
TiO_2	0.23	0.41	-	0.26	0.03
MnO	0.13	0.13	-	0.03	0.03
Fe_2O_3	1.64	2.97	4.30	1.86	0.28
CaO	11.24	35.16	7.30	36.60	53.00
MgO	1.23	1.79	2.00	0.87	0.61
K_2O	0.85	0.78	1.20	0.97	0.13
Na_2O	0.43	-	1.40	0.13	0.04
SO_3	0.78	1.75	0.30	0.56	0.04
P_2O_5	0.07	-	-	0.08	0.06
LOI	9.03	9.13	7.20	30.88	41.90

Closing the loop of concrete recycling within the VEEP project

VEEP European project with the full title of “cost-effective recycling of CDW in high added value energy efficient prefabricated concrete components for massive retrofitting of our built environment” was funded from the first of November 2016 for a duration of 48 months. VEEP main objective is to eco-design, develop and demonstrate new cost effective technological solutions that will lead to novel closed-loop circular approaches for CDW recycling into novel multilayer precast concrete elements (for both new buildings and refurbishment) incorporating new concretes as well as superinsulation material produced by using at least 75% (by weight) of CDW recycled materials.

One of the main activities during VEEP project (following C2CA and HISER) is to design and upscale a mobile HAS pilot plant. This pilot plant will be designed and built to guarantee a nominal processing of 3 ton/hour of ADR fine fraction. The HAS pilot plant will be based on the combination of simultaneous heating, grinding and separation process aiming to weaken the cement paste adhered to fine recycled sand (particles <4mm). This facility will be made of three main zones: pre-heating, heating and cooling. The fractions <0.250 mm, which are hardened cement rich particles, will be separated by using the air flow, while organic constitutes (wood, plastic) will be burnt. Cyclones and electrostatic filters will be used to maximize the production of valuable fractions, while minimizing the emission of dust. The whole process will result in the production of very clean sand and hardened cement. Design and upscaling of the HAS technology will be followed by its integration and optimization with the ADR for the simultaneous production of high quality recycled aggregates, sand and hardened cement.

Economic figures

For recycling of concrete, most of the time lack of economic benefits puts constraints on the technology and the business model. The economy of concrete recycling is extremely dependent on the situation and local conditions. In the Netherlands for example, in time, there will be more amount of crushed concrete available in the market. Taking the continual fluctuation in the price of natural aggregate and crushed concrete into account, it is concluded that the maximum cost for the recycling process should not exceed 5 €/ton. Figure 10 shows approximate costs of each unit process in the C2CA process and the selling price of recycled products.

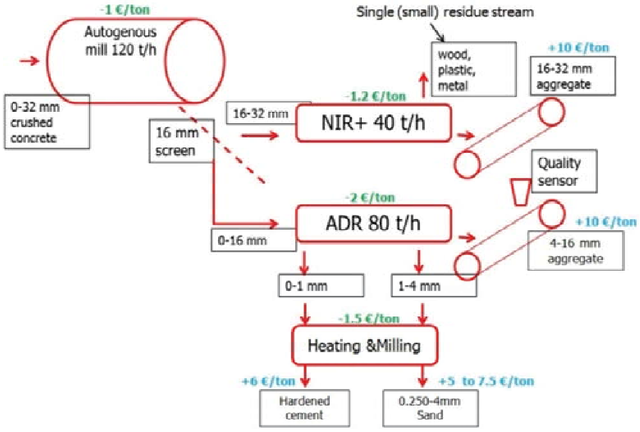


Figure 10. Simplified process flow sheet of the C2CA process. Approximate costs of each unit process and the selling price of recycled products are shown in green and blue colours respectively. The maximum particle size of the crushed concrete as the process input material might change based on the market demand and currently it is changed from 32 mm to 22 mm.

Conclusions

While the C2CA and HISER projects focused on the production of upgraded coarse recycled aggregate, some proof of concept at TRL3 was also performed separating the hardened cement paste and contaminants from fine recycled sand. This proof of concept constitutes the starting point for the new HAS technology proposed in the Horizon 2020 VEEP project, aiming to shift the technology readiness level from TRL3 to TRL5/6. In addition, the novel HAS is expected to produce upgraded recycled sands and supplementary cementitious materials for new concrete production. The ADR technology will be adapted to light-weight concrete waste recycling and the combination of ADR and HAS technology for simultaneous production of coarse and fine recycled aggregates will be an innovative solution in VEEP. At present, according to rough estimates, less than 5% of recycled concrete aggregates are used in new concrete manufacturing. Nevertheless, replacement levels are typically allowed up to 20% or 30% of the coarse fraction of the recycled natural weight concrete aggregate, with acceptable negative effects on visual quality, workability, compressive strength and durability of the mortar and concrete. The C2CA project revealed that the use of the ADR technology can lead to higher quality coarse recycled concrete aggregates for their use in concrete, on the basis that moisture absorbing fine fractions and contaminants are effectively removed from the coarse fractions. That fact can even lead to superior compressive strength that opens up new opportunities for the construction industry. The resulting concrete hardens much faster than concrete made from natural aggregate, while the same amount of cement is being used. It might allow the prefab industry to reduce the use of additional cement or additives and to increase the productivity of the existing facilities. The use of fine recycled concrete fractions in new concrete production is still restricted due to high water absorption, low density and the presence of impurities. The labscale novel HAS technology demonstrated that recycled sands (with absorption values below 3% and without organic fractions) and a potential cementitious powder below 0.25 mm can be produced. The effect of those recycled fractions in cement based materials and new concrete has to be yet studied.

Acknowledgements

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