Recycling of construction and demolition waste: case study in the Port of Antwerp

Jef BERGMANS, Kris BROOS, Peter NIELSEN, Philippe DIERCKX, Yvan BRIJSSE,
Kurt JACOBS

CONTACT

Contact name: Jef Bergmans
Organisation: VITO
Postal address: Boeretang 200, 2400 Mol, Belgium
Telephone: +32 14335616
Email: jef.bergmans@vito.be

EXECUTIVE SUMMARY

Construction and demolition waste (C&DW) represents one of the EU’s largest waste streams. According to the Directive 2008/98/EC on waste, at least 70 percent (by weight) of non-hazardous C&DW must be recuperated by 2020. Eurostat estimates an annual C&DW generation of 970 Mton in EU-27, representing an average value of almost 2.0 ton per inhabitant, with an average recovery rate of 47%. A case study in the Port of Antwerp (PoA) demonstrated new high grade recycling options for purified material fractions from C&DW.

C&DW from the selective demolition of an office building was used for the construction of a new waste collection center. Recovery focused on the mineral fraction of C&DW. This selectively collected mineral fraction was crushed for the production of mixed recycled aggregates (MRA). Currently, MRA are used almost exclusively in low-grade unbound applications like (sub)foundations. However, this market is getting increasingly saturated. Therefore, the development of more high-grade applications is needed to assure a market for the stony fraction of C&DW. The use in these high-grade applications requires recycled aggregates with a higher purity, to guarantee optimal technical and environmental performance.

In order to obtain this higher purity, MRA were treated by advanced automated sorting technologies. Near Infrared (NIR) sorting was used to strongly reduce the content of problematic fractions (e.g. organics, gypsum). These materials can lead to expansive compounds, delays in hardening and a lack of bonding strength in cement-based materials. As a result of the NIR sorting, the technical and environmental quality of the MRA was significantly improved. Subsequently, the purified MRA were treated by color (UV-VIS) sorting. This sorting technique allows the separation of a grey (concrete) fraction and a red (ceramic) fraction. The concrete fraction was then reprocessed into new concrete products that were used for the production of foundation concrete and polished concrete floors, both inside and outside the building. The latter application in particular can be considered as very high level, demonstrating the technical possibilities of pure recycled concrete aggregates.

During the case study, a high-grade recycling option for autoclaved aerated concrete (AAC) was also demonstrated. The major challenge for AAC recycling is sulfate leaching, causing both environmental and technical problems. A strong reduction in sulfate leaching from AAC recycling products was obtained via immobilization. Recycled AAC was used in the case study as a sand replacement in an insulating flooring screed.

This case study illustrates the possible added value of selective demolition and advanced sorting techniques for the creation of high-grade recycling options. Additionally, a recycling pathway for one of the more problematic C&DW types (AAC) was demonstrated.

INTRODUCTION

Construction and demolition waste (C&DW) represents one of the EU's largest waste streams. According to the Directive 2008/98/EC on waste, at least 70 percent (by weight) of non-hazardous C&DW must be recuperated by 2020. Eurostat estimates an annual C&DW generation of 970 Mton in EU-27, representing an average value of almost 2.0 ton per inhabitant, with an average recovery rate of 47% (Pacheco-Torgal, 2014). A large proportion of the stony fraction of C&DW can be easily re-used or recycled as recycled aggregates within the construction sector, be it almost exclusively in low-grade unbound applications such as (sub)foundations. However, this market is getting saturated. Therefore, a shift towards more structural concrete applications (requiring a higher quality of the recycled aggregates) is currently investigated and promoted.

Successful cases of production of recycled concrete based on the use of C&DW recycled aggregates are widely reported in literature (Agrela, 2013) (Silva, et al., 2014) (Silva, et al., 2015). Interest has principally focused on the use of concrete aggregates (Evangelista & de Brito, 2007) (Etxebarria, et al., 2007) (Gonzalez & Etxebarria, 2014), but also the use of mixed recycled aggregates (MRA) is considered (Mas, et al., 2012) (Medina, et al., 2014). In the case of MRA, the sulfate content is often indicated as a restrictive limitation for the use in concrete (Agrela, et al., 2011).

The content of contaminants such as organic matter (wood, plastics, organic foams), gypsum or autoclaved aerated concrete (AAC) in recycled aggregates must be minimized to make these aggregates suitable for high-grade applications. The presence of contaminants can lead to unwanted effects: e.g. cracking, weak points and delay in hardening (Santhanam, et al., 2002) (Kijjanapanich, et al., 2013) (Bullard, et al., 2011).

Several studies indicate that the most effective way of minimizing the amount of contaminants in C&DW materials is selective demolition (Silva, et al., 2014), having a positive environmental impact (Santos & de Brito, 2007) (Coelho & de Brito, 2012). Moreover, policy programs indicate selective demolition as a key factor for C&DW waste minimization. OVAM, the public waste agency of Flanders, states that it is their goal to set selective demolition as the standard in the construction sector by 2020 (OVAM, 2014). This study will describe the selective demolition of an office building in the Port of Antwerp (PoA).

When source separation is not possible, subsequent separation of undesired compounds is necessary to obtain aggregates suitable for high-grade applications. Traditionally, separation is performed by manual sorting cabins, density separators (e.g. windshifters) and/or magnetic separators. However, more rigorous separation might be needed to meet the required levels of purity for high-grade applications.

Advanced automated sorting techniques by colour or chemical composition are successfully researched and developed in other industries (e.g. high quality sorting of plastics, glass recycling) (Niaounakis, 2013). The use of these automatic techniques in C&DW recycling could result in a guaranteed supply of pure recycled materials than can be used in high-grade construction applications. Here, we will assess and discuss the performance of Near Infrared (NIR) and Ultraviolet-Visible (UV-VIS) sorting solutions. The NIR sorting will be used to produce MRA with a higher technical and environmental quality because of lower soluble sulfate contents (mostly related to gypsum and AAC particles) and organic matter contents. Afterwards, UV-VIS sorting will be performed to obtain a concrete (grey) fraction and a ceramic (red) fraction.

Selective demolition and automatic sorting techniques will not only allow the production of high-quality aggregates, but will also produce pure fractions of materials that are currently present as impurities in the stony fraction (e.g. AAC). In the presented case study, a medium sized industrial building was constructed in the PoA, using recycled concrete aggregates in structural concrete and recycled AAC in new floor screed products (Figure 1).

Figure 1: Products with recycled resources used in the construction of a waste collection centre in the PoA.

SELECTIVE DEMOLITION OF AN OFFICE BUILDING

An office building was selected by the PoA for demolition. The demolition was performed selectively in order to obtain reuse possibilities of a number of building elements and recycled aggregates that are usable in high grade concrete applications.

The office building was built in a very traditional Belgian structure. Foundations and most other structural elements consisted of concrete. Bricks and gypsum plasterboard were used for the outer and inner walls respectively. Asbestos containing tiles covered the roof.

The elements to be reused (aluminium window frames, radiators, fire protection doors) were dismantled and removed by hand before the start of the demolition works (Figure 2). This dismantling process took about 1 working day.

Figure 2: Dismantling of the materials that are suitable for reuse.

In a following step, the building was decontaminated. The asbestos containing roof tiles (6 tons) were removed by hand. The roof tiles were put in a container with a plastic coverage preventing dust to be emitted and subsequently transported to a landfill site. Furthermore, mercure containing fluorescent lamps and electronic devices were removed (Figure 3).

Figure 3: Decontamination of the building.

During the subsequent demolition, the inner wall coverage (gypsum plasterboards and XPS insulation boards) wa removed first. These materials can strongly decrease the quality of the stony fraction if not collected separately. Afterwards, the building was demolished with an hydraulic crane, 6 separate fractions were collected: concrete (foundation), a mixed stony fraction (mainly bricks and mortar from the outer walls), aluminium (light fittings), wood (mainly from the roof structure), gypsum plastboards, calorific waste (insulation).

The small size of the office building and surroundings did not allow an economically viable onsite crushing and sieving of the stony fraction. Onsite crushing and sieving is usually performed on demolition sites of >3,000 tons of stony material and enough available space for the machinery. Crushing and sieving of the stony fraction was performed offsite at a recycling site in the PoA.

SENSOR-BASED SORTING TECHNOLOGIES

The NIR sensor-based sorting aims at the selective removal of contaminants (e.g. gypsum, organic material) from the stony valuable particles. Input material is evenly fed onto a conveyor belt, where it is detected by the NIR sensor. The detected impurities are separated from the material flow by jets of compressed air. Particles <6 mm were removed from the samples by sieving. TOMRA performed the sorting treatment of the fractions with particle size >6 mm, guaranteeing both optimal resolution and efficient removal through air jets (Vegas, et al., 2015). Sorting capacities depend on bulk density and grain size of the input fraction, but reached up to 11 ton/h/m in the NIR sorting tests.

Six samples of recycled aggregates from C&DW were collected in 5 different EU countries (Belgium, Germany, Italy, Spain, Sweden). Because selective demolition of the office building did not create a sample of MRA with enough impurities, the Belgian sample (sample 6) was obtained by adding gypsum and AAC particles to the MRA. A big bag of approximately 1 m³ from each sample was sent to the research facilities of TOMRA Sorting GmbH in order to eliminate problem fractions using NIR sensor-based technologies. A representative subsample was taken and used for characterisation. This subsampling was performed in accordance with EN 932-1.

Before and after sorting, the determination of constituents was performed according to EN 933-11. The proportion of each constituent was determined and expressed as a mass percentage.

Figure 4 illustrates the reduction in unwanted constituents (X-fraction: gypsum, organic material, metals) for the six fractions of MRA. Most samples after sorting show reductions in the X-fraction higher than 50%. Sample 2 was the only fraction where the reduction was <50%. This was attributed to the presence of high levels of dark blue AAC (most AAC is white). Since the NIR sensor was not programmed to eject this type of AAC, this particular impurity was not removed.

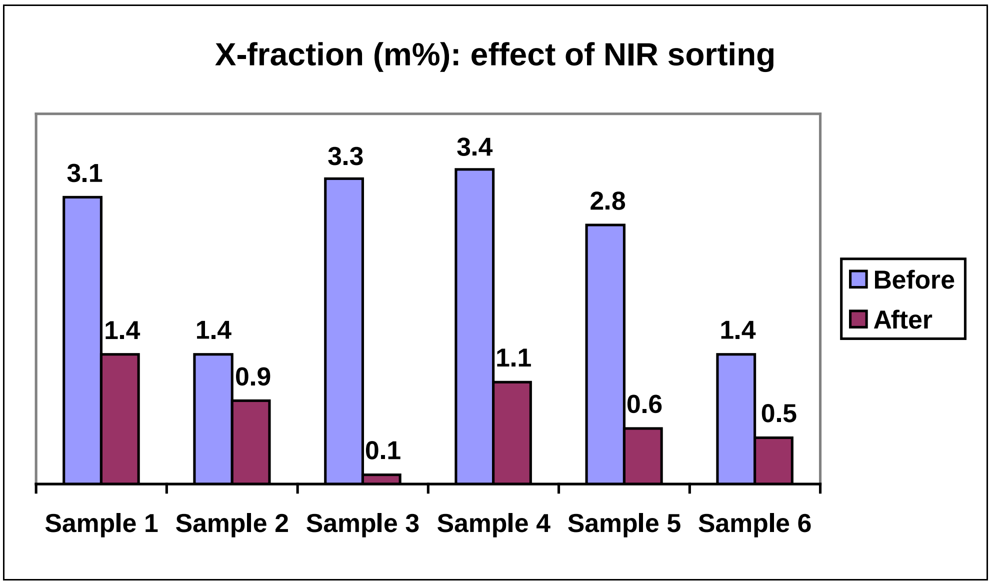

Figure 4: Comparison of the percentage of X-fraction (in m% of the complete sample) before and after application of the NIR sorting technology.

The use of recycled aggregates in high grade construction applications (e.g. concrete, cement bound products) requires low contents of sulfates. Figure 5 shows the amount of acid soluble sulfates determined in the samples. The NIR technology achieves notable reductions in the soluble sulfates by removing large parts of gypsum and AAC.

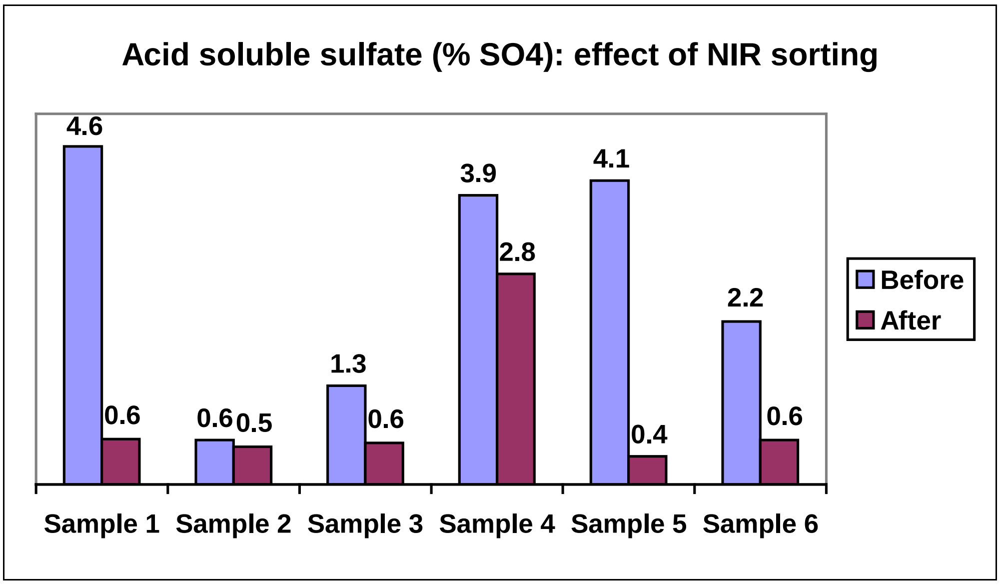

Figure 5: Acid soluble sulfates (in % SO_4) in recycled aggregates before and after the NIR sorting.

The obtained MRA can be upgraded further by using a UV-VIS sensor. By using this technology, the MRA can be separated into a grey concrete fraction wit a purity >97% (Figure 6).

Figure 6: Grey concrete fractions obtained from MRA after UV-VIS sensor-based sorting (left: 6-12 mm, right: 20-35 mm).

PRODUCTION OF RECYLCED AGGREGATE CONCRETE

Afterwards, a waste collection centre was constructed in the PoA, using products with recycled C&DW. The selectively demolished concrete fraction was reprocessed into new concrete products that were used for the production of foundation concrete and polished concrete floors, both inside and outside the building. The latter application in particular can be considered as very high level, demonstrating the technical possibilities of pure recycled concrete aggregates.

The concrete aggregates after selective demolition of the foundation of the office building comply with the standard for “high-quality concrete aggregates” of SB 250, the standard specifications for road works in Flanders (Rc > 90; Rcu > 95; Ra < 1; XRg < 0.5; FL < 2). The produced concretes were ready-mixed and were used in foundation concrete (up to 60 m% replacement of the coarse aggregate fraction) or flooring concrete (up to 30 m% replacement of the coarse aggregate fraction) (Figure 7). No additional measures (e.g. amount of water or cement) were taken for the use of recycled aggregates.

Figure 7: Polished concrete with recycled concrete aggregates in the PoA (left: during construction, right: user-phase).

Initial characterisation tests showed no differences between the different aggregate replacement rates (see Figure 8 for the compressive strength results). The well-documented concrete products can be assessed in time. Up till now, two years after construction, no differences with concrete with natural aggregates was detected.

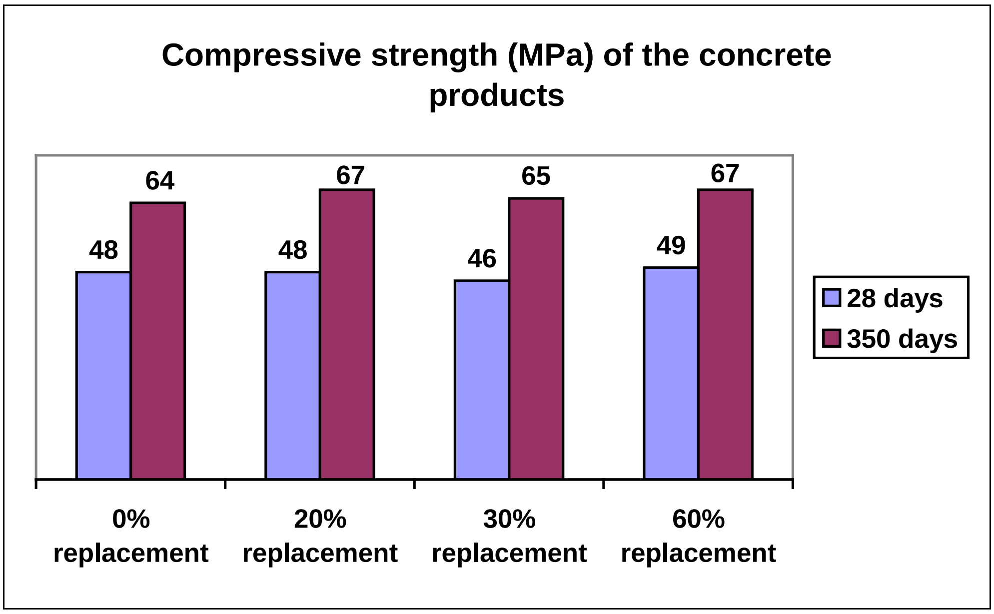

Figure 8: Compressive strength (in MPa) of the concrete products with or without concrete recycled aggregates after 28 and 365 days.

FLOOR SCREED PRODUCTS FROM RECYCLED AAC

Selective demolition allows the production of pure fractions of materials that are currently disposed. The development of recycling options for these fractions would lower the amount of material that needs to be landfilled. One of these materials is autoclaved aerated concrete (AAC). The amount of AAC waste that can be recycled in the production of new AAC is limited because of quality issues. Furthermore, recycling AAC into traditional concrete or as unbound aggregate causes both technical and environmental problems because of the low compressive strength (2-8 MPa) of AAC and its high amount of leachable sulfate: typically > 10,000 mg/kg dm (L/S = 10).

Critical requirements for the immobilization proved to be sufficiently alkaline conditions and the presence of sufficient Portland clinker aluminate (C_3A) to react with the sulfates contained in the AAC. To reach a sufficiently high alkalinity in the developed cement stabilized sand products, the use of CEM I is crucial. The use of blended cements results in a lower leachate pH (<12) and a rise in sulfate leaching. The developed products contained enough reactive aluminate to immobilize the available sulfate. However, when AAC waste is contaminated with gypsum particles, local hotspots of leachable sulfates can create a depletion in reactive aluminium. This results in a strong increase in sulfate leaching.

We developed recycling products containing crushed AAC from C&DW (210 kg/m^3). The crushed AAC (0-8 mm) was mixed with cement, sand and water. During cement hydration a reaction of the AAC leachable sulfate and the aluminate contained in the cement resulted in the formation of (insoluble) ettringite: $Ca_3Al_2O_6 + 3CaSO_4 + 32H_2O \leftrightarrow Ca_6Al_2(SO_4)_3(OH)_{12}.24H_2O$ (ettringite).
The main conditions influencing the formation of ettringite, and hence the leaching of sulfate, were examined. A sufficiently high pH was found to be crucial to meet sulfate leaching standards This high pH was met when using ordinary Portland cement. The presence of additional sulfate as gypsum impurities in the AAC waste proved detrimental towards sulfate leaching.

A floor screed was produced using recycled AAC from a selective demolition and installed in the office building of the waste collection centre (Figure 9). The screed showed a compressive strength of 5.6 MPa and a heat resistance of 2.0 mK/W. The presence of the low-density AAC in the floor screed had a positive influence on its thermal insulation capacities.


Figure 9: The installed floor screed with recycled AAC in the case study.

CONCLUSION

This case study illustrates the possible added value of selective demolition and advanced sorting techniques for the creation of high-grade recycling options. Additionally, a recycling pathway for one of the more problematic C&DW types (AAC) was demonstrated.

In this case study, a selective demolition of an office building was performed, allowing to obtain reusable items and high-grade aggregate fractions that can be used in structural concrete applications. A prior decontamination ensured safe work conditions and recycled products.

Sensor-based sorting technologies proved to be able to produce very pure high-grade aggregates. NIR sorting lowered the amount of unwanted contaminants (X-fraction: gypsum, organic materials, metals) by half, while UV-VIS sorting allowed the production of a grey concrete fraction with a purity of >97%.

The concrete aggregates after selective demolition were used in foundation concrete (up to 60 m% replacement of the coarse aggregate fraction) or polished flooring concrete (up to 30 m% replacement of the coarse aggregate fraction). Initial characterisation tests showed no differences between the different aggregate replacement rates and concrete with natural aggregates while no additional measures taken for the use of recycled aggregates.

Furthermore, a new recycling route for AAC waste was developed. Crushed recycled AAC was used as a sand replacement in floor screeds. The main problem for the recycling of AAC is the presence of leachable sulfates. These sulfates were immobilized by the formation of ettringite by combination with Portland cement. The use of recycled AAC can have a positive effect on the heat insulating capacities of constructions.

The developed products were all used in the construction of a waste collection centre in the PoA. This case study shows a good example of the opportunities for high-grade recycling of pure C&DW fractions and allows a further follow-up on long term performance of the developed products.

ACKNOWLEDGEMENTS

The authors express their gratitude to the EU FP7 project IRCOW (Innovative Strategies for High-Grade Material Recovery from Construction and Demolition Waste - grant agreement no. 265212) for funding the research presented in this paper.

REFERENCES

Agrela, F., 2013. Properties of concrete with recycled aggregates. In: *Handbook of Recycled Concrete and Demolition Waste.* Woodhead Publishing, pp. 304-329.

Agrela, F., et al., 2011. Limiting properties in the characterisation of mixed recycled aggregates for use in the manufacture of concrete. *Construction and Building Materials,* 25(10), pp. 3950-3955.

Bullard, J., et al., 2011. Mechanisms of cement hydration. *Cement and Concrete Research,* Volume 41, pp. 1208-1223.

Coelho, A. & de Brito, J., 2012. Influence of construction and demolition waste management on the environmental impact of buildings. *Waste Management,* 32(3), pp. 532-541.

Etxebarria, M., Vazquez, E., Mari, A. & Barra, M., 2007. Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. *Cement and Concrete Research,* Volume 37, pp. 735-742.

Evangelista, L. & de Brito, J., 2007. Mechanical behaviour of concrete made with fine recycled concrete aggregates. *Cement and Concrete Composites,* 29(5), pp. 397-401.

Gonzalez, A. & Etxeberria, M., 2014. Experimental analysis of properties of high performance recycled aggregate concrete. *Construction and Building Materials,* Volume 52, pp. 227-235.

Kijjanapanich, P., et al., 2013. Biological sulphate removal from gypsum contaminated construction and demolition debris. *Journal of Environmental Management,* Volume 131, pp. 82-91.

Mas, B., Cladera, A., del Olmo, T. & Pitarch, F., 2012. Influence of the amount of mixed recycled aggregates on the properties of concrete for non-structural use. *Construction and Building Materials,* Volume 27, pp. 612-622.

Medina, C., et al., 2014. Influence of mixed recycled aggregate on the physical – mechanical properties of recycled concrete. *Journal of Cleaner Production,* Volume 68, pp. 216-225.

Niaounakis, M., 2013. Physical Recycling. In: *Biopolymers Reuse, Recycling, and Disposal.* William Andrew Publishing, pp. 151-166.

OVAM, 2014. *Materiaalbewust bouwen in kringlopen.*

Pacheco-Torgal, F., 2014. Eco-efficient construction and building materials research under the EU Framework Programme Horizon 2020. *Construction and Building Materials,* Volume 51, pp. 151-162.

Santhanam, M., Cohen, M. & Olek, J., 2002. Mechanism of sulphate attack: a fresh look. Part 1: Summary of experimental results. *Cement and Concrete Research,* Volume 32, pp. 915-921.

Santos, A. & de Brito, J., 2007. *Building deconstruction in Portugal: a case study.* Lisbon, Portugal SB07. Sustainable Construction, Materials and Practices.

Silva, R., de Brito, J. & Dhir, R., 2014. Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. *Construction and Building Materials,* Volume 65, pp. 201-217.

Silva, R., de Brito, J. & Dhir, R., 2015. Tensile strength behaviour of recycled aggregate concrete. *Construction and Building Materials,* Volume 83, pp. 108-118.

Vegas, I., et al., 2015. Upgrading the quality of mixed recycled aggregates from construction and demolition waste by using near-infrared sorting technology. *Construction and Building Materials,* Volume 75, pp. 121-128.