

Closed Cycle Construction - A concept for the separation and reuse of C&D waste

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Abstract

In The Netherlands, construction and demolition (C&D) waste is already to a large extent being reused. Especially the stony fraction is crushed and reused as a road base material. In order to increase the percentage of reuse of the total C&D waste flow to even higher levels, a new concept has been developed. In this concept, called 'Closed Cycle Construction', the processed materials are being reused on a higher quality level and the quantity of waste that has to be disposed of is minimised. For concrete and masonry, the new concept implies that the material cycle is completely closed, and the original constituents (clay bricks, gravel, sand, cement stone) are recovered.

The new concept has several benefits from a sustainability point of view, namely less energy consumption, less carbon dioxide emission, less waste production and less land use (for excavation and disposal sites). Economically the new process is more or less comparable with the current way of processing C&D waste.

On the basis of the positive results of a feasibility study, currently a pilot and demonstration project is being carried out. The aim is to optimise the different process steps of the Closed Cycle Construction process on a lab scale, and to verify them on a large scale. The results of preliminary experiments are promising.

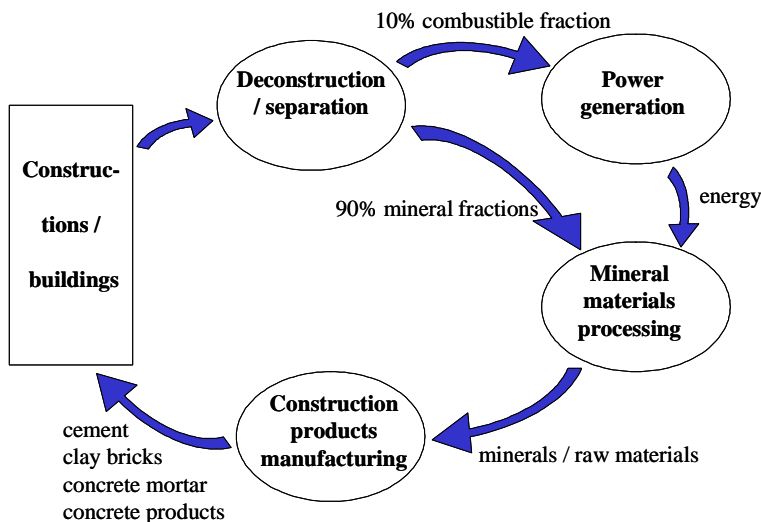


Figure 1: Basic principle of the Closed Cycle Construction concept

1 The Closed Cycle Construction concept

The new concept, called 'Closed Cycle Construction' is principally based on closing the material cycles for especially masonry and concrete in the construction sector. Besides, also the remaining mineral fractions of C&D waste are being re-utilised. In short this means that, after deconstruction / demolition of a building, concrete rubble, masonry debris and mixed stony rubble are separated and treated individually, gaining minerals that can be re-used as raw materials for the manufacture of new construction products (clay bricks and concrete). One of the most remarkable benefits of the new concept is that the thermal process steps are fuelled with the combustible fraction of the C&D waste itself. The concept is visualised in figure 1.

In fact, in the Closed Cycle Construction concept four different C&D waste streams are distinctly processed, namely clean concrete rubble, clean masonry debris, mixed rubble and mixed C&D waste (also including wood, plastic, plasterboard, glass, etc.). This is shown in figure 2.

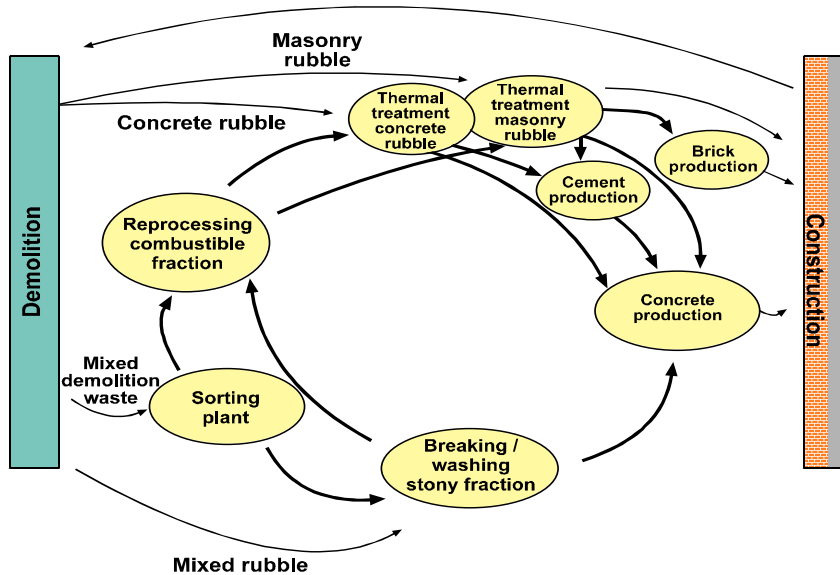


Figure 2: Distinct treatment of four different C&D waste streams

For concrete, this new technology involves a rotary kiln in which the uncontaminated concrete rubble is thermally treated at a temperature of about 700 °C to dehydrate the cement stone. The concrete rubble pieces disintegrate and the original components are set free. After treatment, only 2 % of hardened cement paste remains attached to the sand and gravel grains.

For masonry debris, the new technology consists of a three-step process. In the first step, the large pieces of debris are thermally treated at a temperature of about 500 °C, to set free the majority of the original ceramic bricks. These whole bricks can be used for restoration purposes or for the construction of buildings in an old fashioned appearance. Subsequently, the remaining pieces of brick and mortar are physically separated.

In the third step, the remaining ceramic fraction is crushed and reused as raw material for the production of new ceramic bricks.

To be able to process the entire supply of C&D waste, the above mentioned processes have to be implemented in an overall process. This overall process also includes process steps for the treatment of mixed C&D waste. The mixed C&D waste streams are separated and decontaminated. For this purpose several dry density separation techniques are being developed. The quality of the stony fraction is improved to a level that it can be re-used as an aggregate in concrete.

For demolition waste that has not been separated at the source, advanced detection and separation techniques are being developed, to sort out contaminants like gypsum and hazardous materials. The remaining material is divided into a heavy (stony) fraction and a light (combustible) fraction. The combustible fraction (wood, plastic, paper, bituminous roofing material) is cleaned up and prepared as a fuel for the thermal process steps.

2. Thermal treatment of concrete rubble

To be able to close the material cycle for concrete completely, high quality raw materials must be produced from concrete rubble [1]. These raw materials need to fulfil the criteria that are set for primary raw materials. For this reason, a thermal process has been developed for the treatment of concrete rubble.

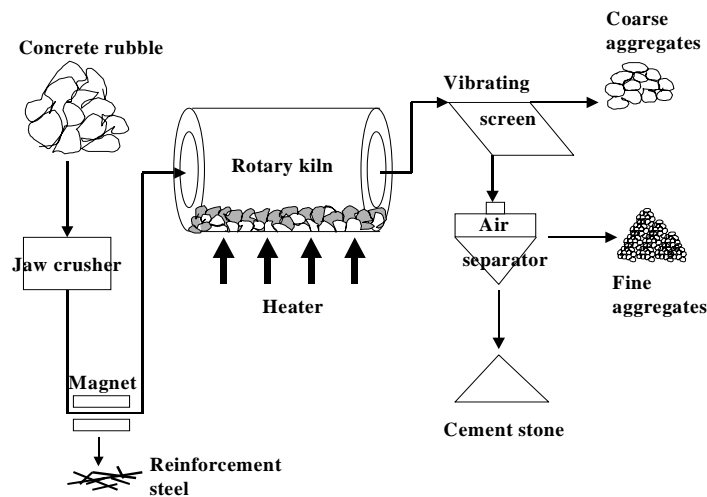


Figure 3: Flow scheme of thermal treatment of concrete rubble

The process step suitable for setting free the different components of concrete is based on the input of a combination of thermal and mechanical energy. As is schematically shown in figure 3, the installation exists of the following unit operations:

- a jaw crusher to reduce the size of the coarse concrete rubble to below 10 cm;
- a magnet, to remove any reinforcement steel present in the concrete rubble;
- a rotary kiln for the combined input of thermal energy (to disintegrate the matrix) and mechanical energy (to further release the different concrete components);
- a vibrating screen and air separator to separate the three fractions: coarse aggregate (primarily gravel), fine aggregate (sand) and cement stone.

The proposed process is based on the experiences of Mitsubishi, TNO and KEMA [1][2]. The heating step must be performed on a temperature of as least 700 °C to obtain clean aggregate fractions (sand and gravel) [1]. Preliminary investigations on a laboratory scale in which the concrete rubble was treated at 700 °C, showed that from 1 ton of concrete 450 kg gravel (> 4 mm), 350 kg sand (< 4 mm), 130 kg cement stone (< 150 μm) and 10 kg reinforcement steel can be recovered [1]. The remaining 60 kg was originally present as hydration water, and was emitted as vapour. If the concrete is treated at a relatively high temperature (> 750 °C) there is hardly any residual cement paste left attached to the aggregate grains. In that case, the gravel and sand are supposedly of the same quality as primary gravel and sand. The performance of the recovered aggregate however has to be verified experimentally [3]. The dehydrated cement stone fraction can be used as a substitute for part of the Portland cement clinker in the cement production process. The cement stone can be directly fed to the Portland cement mill. This saves a lot of energy and raw materials.

3. Thermal treatment of masonry debris

In co-operation with the Technical University in Delft, at TNO a PhD study was carried out into recycling options for masonry debris [4]. The aim of the process development was closing the material cycle for ceramic clay bricks within the production chain. This resulted in a three-step process, as it is visualised in figure 4, and described in more detail in the next paragraphs.

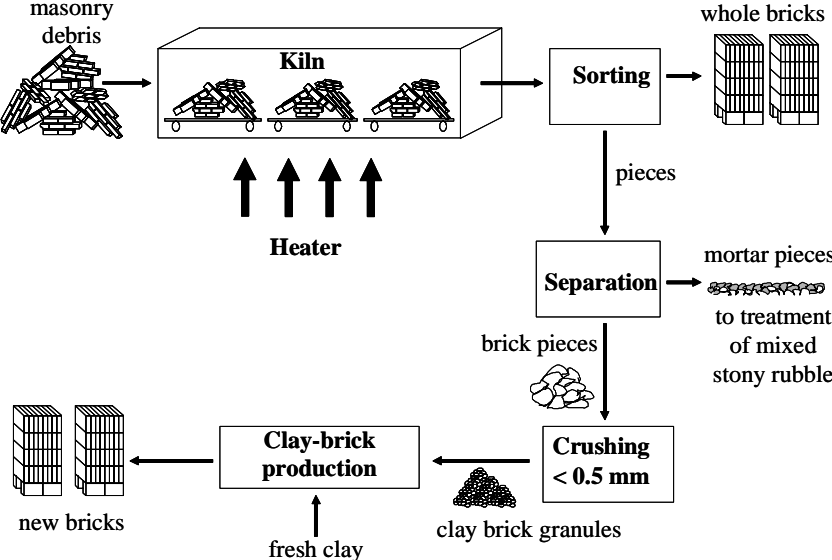


Figure 4: Process scheme of the treatment and recycling of masonry debris

The first step in the recycling of masonry debris is a thermal process, to recover whole bricks. The process is based on the difference in linear expansion coefficient between mortar and brick. This means that with increasing temperature, strains are built up in brick and mortar, causing shear stresses on the interface. Because of the fact that this

interface, in general, is the weakest part of the masonry, this phenomenon leads to crack formation on the interface, setting free the whole bricks.

In the laboratory, optimum process conditions were determined. Especially the temperature, required to separate all the mortar from the brick's surface, was investigated for different brick types and different mortar systems. It appeared that, in general, the best temperature was around 540 °C. However, some mortar types require even higher temperatures. This leads to a relatively high percentage of cracked bricks, because of the fact that the critical quartz solid phase transition temperature of 573 °C must be passed twice, leading to internal stress.

To verify the laboratory experiments, an experiment on semi-practical scale was carried out. Two tonnes and a half of masonry debris pieces were piled on kiln cars and fed into a stationary chamber kiln. The masonry debris was treated at 540°C for twenty four hours. After the thermal treatment the bricks were hand sorted. The result was: 900 kg whole bricks, 1120 kg broken bricks and brick parts, 500 kg mortar and some steel anchors. So, the recovery rate was 36% of the total mass of masonry input. The bricks had a grey appearance at the bottom and top side. The facing sides however, were clean. The bricks were of good technical and environmental quality, in accordance with the Dutch standard (NEN 2489), and the Dutch Building Materials Decree.

4. Separation of mixed C&D waste streams

With regard to the separation and further clean-up of the mixed C&D waste streams, several dry density separation techniques were investigated experimentally, on a pilot scale [5]. All investigated separators showed variable but satisfactory efficiency. The best choice depends on a trade off between economy and required product quality, and on factors such as space requirements, capacity requirements, whether or not classification in narrow size fractions is possible, etc. The tests resulted in sufficient quantitative data to support a tailor made decision for a given operation.

The **dry sand fluidised bed** shows the highest product purities for 20 mm oversize and obtains product qualities that are similar to wet jigging. The principle ability to separate coarse material (larger than 50 mm) is unique for this dry technology and is of high relevance for C&D waste sorting. Unfortunately separation of larger sizes than 40 mm could not be investigated in the present project due to practical limitations of the applied equipment. Disadvantage is sand loss in the product and the lower efficiency for finer material (5 to 20 mm). However, in aggregates a certain sand level is tolerated and in combustible fractions it causes only a minor increase in ash content.

Although of lower separation efficiency, the **air jig** provides a favourable solution when prior classification into several size fractions is impractical and a significant fines percentage (2 to 20 mm) is present, for which the fluidised bed is unsuitable. Both separators would also work well together, the jig treating the material up to 30 mm, the fluidised bed the 30 mm oversize. Prior removal of lights and fines with **air sifting** is recommended.

Ballistic separators and **air tables** require prior classification into rather narrow particle size fractions. A high screening efficiency is of paramount importance. For damp feed appropriate screening technology must be applied. **Air tables** show additional displacement of tile and glass fragments in the lights. **Ballistic separation** is very suitable as high volume pre-concentration wherever narrow classification can be done and there is sufficient head-room available.

The extraction of components based on **automatic colour sorting** proved effective for coloured brick and tiles. For the latter two-sided detection is recommended. Also glass can be removed at high efficiency, but a second purification stage will be needed to obtain a saleable glass product. Gypsum levels in aggregate can be lowered by almost a factor 20, but cannot be concentrated in a saleable gypsum product in a single stage. In a second stage gypsum must be separated from aggregate of the same colour, for instance by means of density separation.

5. Benefits of 'Closed Cycle Construction'

The new concept as a whole has several advantages. The most illustrative advantages are:

- Closing the material cycles for concrete and masonry within their own chain. With regard to the framework of sustainable development, this fulfils one of the objectives of the Dutch government. It also fits into the industries policy of producer's responsibility and long-term raw materials availability.
- Recovery of high-grade raw materials for the production of new concrete and ceramic bricks means higher profits for the C&D waste treatment industry, because of higher prices for their products. The production of high-grade raw materials also reduces the excavation of primary materials, such as sand, gravel, clay and marl.
- Utilising the combustible fraction of demolition waste as a fuel doubles the environmental profit. First, in reducing the amount of waste to be disposed of, and second in reducing the amount of fuel that is required for the thermal treatment of concrete and masonry rubble.
- Re-use of the recovered cement stone fraction in the production of new cement (as replacement of part of the Portland cement clinker) leads to less excavation of marl, and less carbon dioxide emissions.
- The integrated character of the process finally implies a reduction in transport costs. This means less fuel consumption and less exhaust gases.

6. REFERENCES

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