

Refiring bricks at 540°C



by **ASTRID VAN DER GRAAF**

For many decades, stony debris from building and demolition sites was reused as road building material. Until recently there was no need to look for other uses for this mixture of concrete and masonry rubble. However, now that our supplies of marl and gravel (two of the three ingredients of mortar and concrete) are dwindling and prices are beginning to rise, the concrete industry is showing a growing interest in ways to recycle concrete rubble. Since masonry rubble can only be used as a granulate for road construction in combination with concrete rubble, a vision of a masonry rubble heap without any takers looms ahead if no alternative application is found. Anticipating the problem, civil engineer Koen Van Dijk of the Civil Engineering Materials Science department at TU Delft has developed a number of processing techniques for reusing masonry rubble. Van Dijk was recently gained his doctorate for developing a process that can extract 50% of the bricks from masonry debris from buildings that have been dismantled selectively. He also uses a magnetic technique to extract the brick fraction from the remaining masonry debris. Mixed with fresh clay it becomes the raw material for a new generation of bricks, thus closing the clay brick cycle.

Each year 23 million tons of construction and demolition waste are produced in the Netherlands. The stony fraction of the rubble is about 70%. The Building Materials Decree stipulates that as of the year 2000 reusable waste may no longer be dumped as landfill. Since it may not even be transported across provincial boundaries, municipal authorities were left with few options apart

The Netherlands produces approximately 16 million tonnes of stony building and demolition waste each year. Most of this comes from buildings erected during the nineteen-thirties, sixties, and seventies. Buildings from the nineteen-sixties are characterised by their high concrete content, whereas during the nineteen-thirties masonry was almost exclusively used.



The large stream of demolition waste has made the recycling industry into a flourishing trade with a modern approach. Whereas previously the waste would be removed in mixed form to be sorted elsewhere, these days mobile waste separator plants are moved in to extract useful end products on site.

from the obvious one, which was to use all of it for road construction projects. The volume of construction and demolition waste is sufficient to construct a six-lane motorway 340 kilometres long, i.e. the length of the Netherlands, every year. However, now that the government has decided not to build any more roads to tackle the congestion problems, the demand for road construction granulate will inevitably drop. On the other hand, the supply will not, according to Dr. ir. Koen Van Dijk.

Delft Ladder 📌 In anticipation of this development, the TU Delft and TNO Environment, Energy & Process Innovation, based at Apeldoorn, started a research programme to investigate the possibilities for high-quality, sustainable reuse of stony debris.

Although road construction granulate is a useful application, it remains a low-quality form of reuse from the point of view of sustainability. Recycling involves reusing the waste material for the same purpose as it originally served, in this case by having the waste material continue as construction material in its own cycle. This is the only way to close the cycle.

In doing so Van Dijk is introducing the 'Delft Ladder', the modern-day successor to Lansink's Ladder, which dates from 1979, when legislation to control the use of waste materials was introduced. In this context, the use of concrete rubble for the production of concrete is a high-quality form of reuse. Van Dijk's supervisor, Prof. Dr. Ir. Charles Hendriks of the Civil Engineering Materials Science department, is one of the people behind the current Building Materials Decree and the Delft Ladder.

Concrete 📌 The stony rubble produced by demolition activities generally contains about 65% concrete rubble and 35% masonry debris. According to Van Dijk, reuse of crushed concrete rubble is now a viable option, although there is still room for improvement. Broken and crushed concrete rubble produces a jagged granulate in which the particles do not move smoothly against each other.

Van Dijk: "Concrete must be fluid. We measure its consistency by pouring the concrete mix into a conical cylinder, which is then removed. The extent to which the concrete then settles, tells us something about its consistency. Each application demands its own degree of liquidity. For example, a floor requires a higher consistency than a column or a beam."

By adding a superplasticiser, a kind of lubricant, the consistency can be increased while maintaining the water/cement ratio. Van Dijk's colleague, doctorate student Hiroshi Ishiguro, is looking further into this part of the stream. The main problem when processing concrete debris is the remaining mountain of masonry debris, which is unsuitable for use as road construction granulate due to its low compression strength and high water absorption rate.

The weakest link 📌 The bond between bricks and mortar is the weakest link, one that has presented many a (DIY) bricklayer with all sorts of problems. If the brick is too dry, it extracts too much water from the mortar. As a result, the cement at the brick face receives too little water when it sets (hydration), and produces a weak bond. If, on the other hand, the brick is too wet, the mortar in contact with the brick receives an excess of water, resulting in cavities as the water evaporates. In fact, it is practically impossible to get it just right, according to Van Dijk, so the lesser of the evils is the thing to go for. As he was supervising a first-year lab session, Van Dijk got the idea of heating lumps of masonry.

"The students had been asked to measure the linear expansion coefficient of an aluminium beam, which is a standard lab assignment. And then I suddenly got the idea, if all materials have different expansion coefficients, why shouldn't bricks and mortar? And if the difference is big enough, the resulting stresses will break the bond."

Burnt shells 📌 "Under laboratory conditions, the masonry spontaneously fell apart after being heated to a temperature of 540 °C in a gas kiln. This temperature raises the stresses to a maximum, and you can hear the mortar bricks bond break loose. Afterwards, you can simply pick the mortar off the bricks in slabs, leaving the bricks almost perfectly clean. The only blemishes are where the mortar water has seeped into the brick, leaving a grey bloom.

The trick only works with cement-based mortar, which is a hard material, creating stresses between the bricks and the mortar.

"The old-fashioned lime mortar, which is made from burnt shells and sand, is



One of the most important end products is mixed granulate. This consists of at least 60% concrete granules and up to 40% mixed bricks and mortar fraction. It is used as a foundation material for road construction. However, the number of road construction projects is decreasing, and with it the market for the recycling industry.



The concrete industry is not an alternative market for the mixed granulate, due to the high content of bricks and mortar. The industry is interested in the pure concrete fraction however, but this still leaves the brick fraction to be disposed of.



The demolition industry is also looking for alternatives, one of which is selective demolition. During the demolition of a simple structure at the Boezembocht marshalling yard in Rotterdam, various waste streams were extracted separately during the actual demolition process.



With a view to reuse, large chunks of masonry were extracted in one piece and sent to the brickworks. The remaining fractions to be extracted were concrete rubble, mixed stony rubble, metal, steel beams, roofing materials, wood in a number of graded qualities, and a mixed residual fraction.



much softer and follows the expansion of the bricks. Anyway, lime mortar is easily removed by hand, which is how bricks reclaimed for restoration projects are processed. These days however, 80% of all masonry uses (Portland) cement mortar, which cannot be removed by hand.”

Experiment 🦋 Van Dijk put his theory to the test in Rotterdam, where an old building on the ‘Boezembocht’ railway marshalling yard was being demolished. Van Dijk had arranged for the masonry to be selectively demolished. Timber, metal, and plastic materials are always selectively stripped, but the concrete and masonry shell usually gets crushed to bits and carried off as debris. For his field experiment, Van Dijk needed a couple of tons of ‘unbroken’ parts of wall that could be stacked on top of lorries and carted into the gas kiln. This meant that the demolition plant had to remove the outer leaf of a cavity wall as a separate piece, which can be tricky if both leaves are connected with anchors. For his thermal treatment of the lumps of masonry, Van Dijk got the support of one of the largest manufacturers of bricks and roof tiles in the Netherlands, Terca Brick in Reuver, Limburg, whose technical manager, Ing. Fons Wagener was a member of Van Dijk’s supervisory committee. Using a thermal treatment procedure involving 3 hours of heating up, 2 hours at 540 °C, and then the cooling stage, he managed to reclaim 45% of the bricks from the masonry in one part. Not a bad result for the first field test.

Firing bricks

Fresh bricks are fired for 40–60 hours at a temperature between 1,000 and 1200 °C, depending on the type of clay used. The unfired bricks are stacked on kiln lorries that run on tracks through a 120-metre long tunnel kiln. At the first stage, the dried clay bricks are slowly heated to remove any free, physically or chemically bound water. Up to 100 °C the free water, i.e. the water between the clay granules, evaporates. Between 100 °C and 250 °C the physically and chemically bound water disappears. As a result, the brick shrinks by a few percent. Any organic material left in the clay burns off as the temperature is increased to 250 or 500 °C. Heating to full temperature takes about 20 hours in all, the same time as the cooling down stage takes, although it varies according to the type of clay used. Next to the evaporation of water, the so-called quartz phase transition that occurs during heating and cooling is a major factor affecting the success of the firing process. The transition occurs at 573 °C, when alpha quartz transforms into beta quartz, abruptly expanding its molecular structure. During the heating phase, there is less risk of cracking than there is during cooling since the compression stresses resulting from the transition are easier to absorb while the particles are still relatively loose. During cooling, the tension caused by the shrinkage associated with the quartz phase transition will more easily cause damage. During the actual firing stage, or solid-phase sintering, molecular bonds are formed between the clay particles. Dr.ir. Koen Van Dijk: “It is a bit like leaving a bag of sweets in a car on a hot day. At the points of contact, the sweets will stick together, and if you try to take one out of the bag, you’ll find the whole lot clinging together.” To ensure proper adhesion between the particles, a lutum content of 10% is required. Lutum is the fraction of particles with diameters of 10 micrometres or less. The smaller the particles, the better the green strength before firing, and the higher the quality of the brick. However, at higher lutum levels, the risk of cracking due to shrinkage during drying increases.

Subtle demolition 🦋 The thermal method for reclaiming bricks is advantageous from an energy point of view. Also, it requires less energy than is required to fire new bricks (see separate box). The drawback is that the breakers, the recycling companies, have to ensure that parts of walls are retrieved in one piece from a demolition site. After all, subtle demolition is a contradiction in terms. Before the process can be applied in the real world, research will have to be done into developing a new approach to demolishing buildings, according to Dr. Peter Rem of the Raw Materials Technology section at the faculty of Applied Earth Sciences. Rem specialises in the deployment of tested and tried separation techniques from the mining industry for new applications. He thinks it is not such a bad idea to heat a building in its entirety.



To recycle the masonry rubble, a thermal process was developed by TU Delft in collaboration with TNO to extract the bricks from the masonry rubble. The masonry was subjected to a heat treatment in the chamber kilns of the Terca window lintel factory at Reuver, Limburg, in the south of the Netherlands.



In three hours, the rubble was heated to a temperature of 540 °C. After two hours at that temperature, the cooling stage followed. The bricks, which had been stacked high inside the kiln, had broken apart from the mortar and tumbled from the kiln lorry.



The cracks at the brick/mortar interface are the result of the difference in linear expansion coefficient.



By reclaiming the retro bricks, the recycling loop has been successfully closed. It is now up to the industry to apply the method in the field.

“It may sound strange, but from a logistics point of view it makes sense. If the integral heating of a building becomes part of the demolition process, it stands a good chance of success. The process is simple: wrap up the building and turn up the heat.”

Magnetic bricks ¶ Even so, a large part of the masonry remains as rubble. While searching for a suitable method to separate the remaining bricks and mortar from each other, Van Dijk came into contact with Rem. The ideal separation technique was easily decided when it turned out that clay contains about 5% iron.

Rem: “Magnetic separation is used in the mining industry to extract ilmenite (FeTiO_3 – ed., AvdG). To separate bricks and mortar properly, the rubble must be crushed into particles with a diameter of no more than 2 millimetres, otherwise the magnet will not be able to handle them. You need a steep magnetic gradient, and as a result the useful field is very narrow. Surprisingly, all bricks are magnetic, even the yellow ones, which you would expect to contain less iron, as their lime content is much higher.”

An iron content of 2-3% turns out to be sufficient to separate masonry rubble into brick granulate and mortar grit.

Van Dijk: “If the difference in magnetic susceptibility is big enough, materials can be separated using a magnetic field. The average magnetic susceptibility of bricks is $550 \cdot 10^{-9} \text{ m}^3/\text{kg}$, and that of cement mortar is $17 \cdot 10^{-9} \text{ m}^3/\text{kg}$. This enabled us to achieve an efficiency of 90% for separating bricks from cement mortar.”

What remains now is a large container of pure brick granulate of 2 mm or less in diameter. Van Dijk used this to fire his own bricks, with the support of the ceramics department of TNO-TPD at Eindhoven, and Terca Brick. In order to find the ideal mixture of clay and brick granulate, Van Dijk tested a number of variations of clay types, quantities, and types of granulate.

“In the lab, we were still able to obtain good-quality bricks using 95% brick granulate and 5% new clay. These met the various product specifications such as compression and tensile strength, resistance to frost damage, and water absorption. In practical conditions, however, 50% recycled material turned out to be the limit.

“This has to do with the ‘green strength’, which is the strength of the dried clay brick,” Van Dijk explains.

Green strength ¶ The natural colour of clay is greenish. After the fresh clay, or in our case, the granulate mix, has been formed by pressing it into a brick mould and releasing it, the wet brick must dry before it can go into the kiln. The dried, ‘green brick’, must have a tensile strength of at least 0.5 N/mm^2 , because it needs to withstand the internal transport through the brickworks and also to survive the stacking inside the kiln. Speaking of colours, the red colour of the brick we all know so well is produced by the firing process inside the kiln. There are two different ways of firing bricks: oxidising, which means that extra oxygen is added to the kiln, and reducing, which takes place in a closed environment with a shortage [***depleted****?] of oxygen. During an oxidising firing, the iron in the clay reacts with the added oxygen to form iron oxide (FeO), which has a red colour. During a reducing firing, the bricks end up blackish due to the elementary iron (Fe). If the bricks contain a lot of lime, the resulting calcium oxide (CaO) turns them yellow, and the presence of certain metals such as manganese and copper, lends them a greenish or blueish colour. Van Dijk was surprised to discover that even with a level of yellow brick granulate as high as 75%, the fresh clay type determined the end colour of the brick. “A cross section of the brick shows the yellow particles”

Infrastructure ¶ This closes the cycle, according to Van Dijk, but the path to actual application is arduous, depending as it does on several different parties in the market. The separate reuse of concrete and masonry rubble affects the entire chain, from demolishers, crushers, recycling companies and manufacturers of building materials, right up to builders and architects.

“The linchpin is formed by the recycling companies that process rubble into road construction granulate. For the time being, this remains a lucrative business, witness the number of recycling plants that have seen the light of day since 1995. They get paid both to take in debris from the demolishers, and to supply granulate. But the time is nigh when the demand for road construction granulate will decline as fewer new roads are being built, and the concrete industry ‘demands’ the concrete rubble fraction. This will open the road to recycling of bricks, and will even turn it into necessity.”



At the Kijfwaard brickworks at Pannerden, a test was conducted in which the brick fraction, after being ground, was mixed with clay in a 50/50 mix. Using the common Dutch production method with moulds (because of the soft clay), the mixture can be used to produce bricks. The clay mass is pressed into moulds that have been sanded to make the unfired bricks easier to extract.



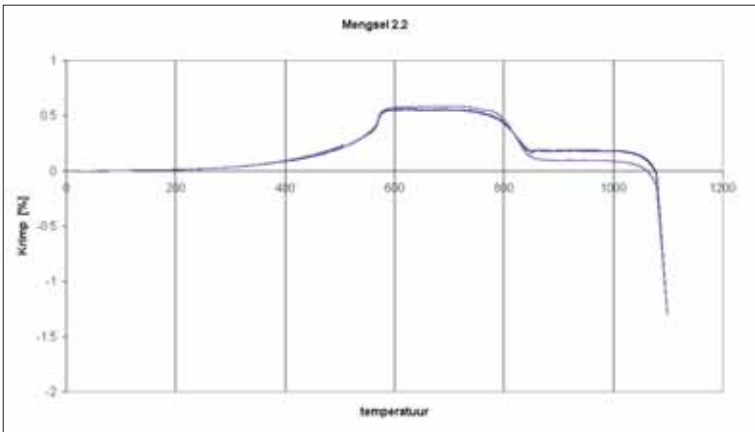
The residual fraction, which consists of broken and damaged bricks and mortar, can be separated into pure fractions of bricks and mortar by means of magnetic separation so research at the Applied Earth Sciences faculty has shown. This is made possible by the fact that the brick particles contain about 3-5% iron, while the mortar particles contain less than 0.5%.



The unfired bricks are left to dry to the atmosphere for several days.



To prevent the 'green' bricks breaking during the internal transport at the factory, they must be sufficiently dried.



During the firing, the quartz contained in the material transforms from its alpha phase to its beta phase, a process associated with sudden expansion.

According to Rem however, it takes a little more than that: “No company in the world is going to launch a product for which there is no market yet, hoping that the rest of the chain will follow suit. To close the cycle will require a coherent infrastructure.” Which is why TNO-MEP, together with seven companies from the chain are working on a method to further develop the concept of a closed material cycle for concrete and masonry.

Guarantees It is not to be expected that the government will force the reuse of bricks.

Rem: “The trend is to loosen legislation and to increase the responsibilities of the market parties. This is a deathblow to innovation. The problem lies in accountability. If in ten years’ time, recycled bricks are found to develop cracks, the builder will be held responsible. The risk simply does not outweigh the cost saved by reuse. The government is the only party that can accept such a responsibility, for example by issuing some kind of product certificate.” Whether the market will use these bricks depends not only on the quality of the bricks, but also on their aesthetic qualities, which may be affected by their slight grey bloom.

“They may well become a success if architects introduce a recycling look instead of bright red,” says Van Dijk. Even so, Van Dijk is certain that there is a bright future for his invention, and he is eagerly following developments. There is little more to do when you develop a solution to a future problem. He now works as a civil engineering consultant at KH Engineering in Schiedam, where he does calculations on various industrial steel and concrete structures. In addition, together with Edwin Swart, who did his doctorate research at the same time as Van Dijk, he runs an architectural and civil engineering consultancy firm, Van Dijk & Swart B.V. where they calculate and design building structures.

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The newly fired fifty/fifty bricks containing 50% brick granulate and 50% clay.



From left to right: the reference brick (pure clay), the fifty/fifty brick containing 50% masonry granulate, and the fifty-fifty brick with 50% brick granulate.

The surface assumes the colour of the fired clay, whereas the sections show brick particles of different colours. The sections have been injected with resin to produce strong polished samples that can be viewed through a microscope.



If the temperature treatment during the firing is rushed, the inside of the product can end up cracked, which affects the mechanical quality of the brick.

