

Carbon dioxide as a stimulus for life cycle thinking in cement and carbon neutral concrete building

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ABSTRACT: Sustainability covers all social, economic and environmental aspects of a product all over its life cycle. It requires both life cycle thinking and multidisciplinary skills. In the cement and concrete industry the key word 'sustainability' is mostly linked to the depletion of natural resources, the use of energy, the reuse of secondary materials and to emissions. Yet there are other faces of cement and concrete. Cement factories are often a place where alternative raw materials and non-fossil fuels are used. And concrete helps to save energy in the use phase. It is time to make a new over-all balance!

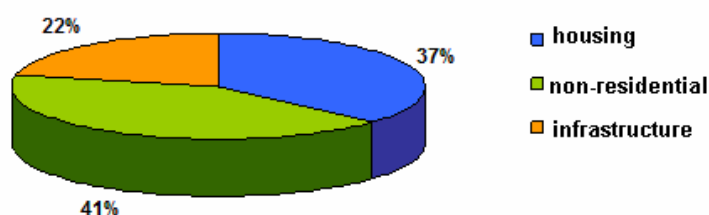
1 INTRODUCTION

Sustainability covers all social, economic and environmental aspects of a product all over its life cycle. It requires both life cycle thinking and multidisciplinary skills. In some branches the focus is on social aspects, for instance in the textile industry. It makes people think of how clothing is made; by skilled but expensive European hands, by skilled and cheap Chinese hands, or by children's hands in India. In other branches the emphasis is on environment, for instance in the chemical industry.

In the cement and concrete industry the key word 'sustainability' is mostly linked to the depletion of natural resources, the use of energy, the reuse of secondary materials and emissions. In the construction industry the context is more or less the same.

A couple of cities in the Netherlands have already committed themselves to statements like 'our city/village/offices/buildings will be climate neutral in 2015 ... 2018 ... 2020'. Well, this will no doubt require a lot of out-of-the-box thinking, creativity and a strong determination to make maximum use of ready-to-implement solutions to reach these ambitious goals.

Climate neutral concrete (CNC) perfectly fits in this range. CNC itself might contain (some) embedded energy, but in the application phase CNC may save so much energy that the life time balance is positive again.



Concrete manufactured in the Netherlands

Please remember that more than 37% of all concrete manufactured in the Netherlands finds its way to the housing sector. That is about 5,5 mln m³.



Another 41% is applied in non-residential buildings. A sector that puts such huge quantities of materials on the market is morally, if not legally, obliged to think about the consequences for mankind.

In 2007 the Cement&BetonCentrum started a campaign on the sustainability aspects of cement and concrete. The main impetus comes from the increasing public awareness of the green house effect.

What we would like to show is that an assessment of the properties and qualities of concrete can only be done in an integrated way, i.e. from the cradle to the grave and taking into a balanced account of the three pillars of sustainability: people – planet – profit.

Within the limited framework of this publication and for reasons of simplicity we here focus on environment, more specifically on the carbon footprint of concrete.

2 THE VALUE CHAIN

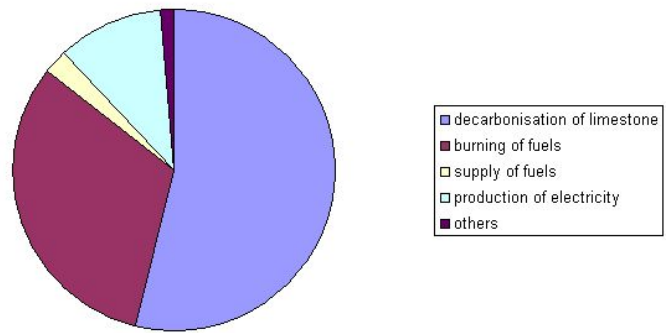
2.1 Cement

A rule of thumb in worldwide cement manufacturing is that the cement industry contributes around 5% of the emission of man made CO₂ on earth. The worldwide average, however, is absolutely not the same as in Europe or even in Holland. It is just around 1% in The Netherlands. Imports from cement, low clinker content and the use of biomass play a role here.



Is 5% much? That fully depends on the framework. Could it be less? In percentage yes, in total probably not. It is expected that there will be an increase in cement and concrete consumption of 100% in the next 45 years, mostly outside Europe and the US. In 2000 the world already needed some 5 billion m³ of concrete. *That's 5 cubic kilometres.*

Where does the CO₂ in the cement industry come from?



Distribution of Global Warming Potential per ton of representative average European cement, total = 761 kg CO₂ eq; (Source: Cembureau 2007)

There are two main sources: fuels and limestone. The clinker burning process requires flame temperatures of around 2,000 °C. The output of a cement kiln is between 3,000 – 5,000 tons per day. In Europe the Portland clinker burning process demands around 3,600 MJ/t clinker, corresponding with 725 – 930 kg CO₂/t.

Approximately 35% of the carbon dioxide emitted by the cement industry originates from the burning of fuels, partially being fossil fuels.

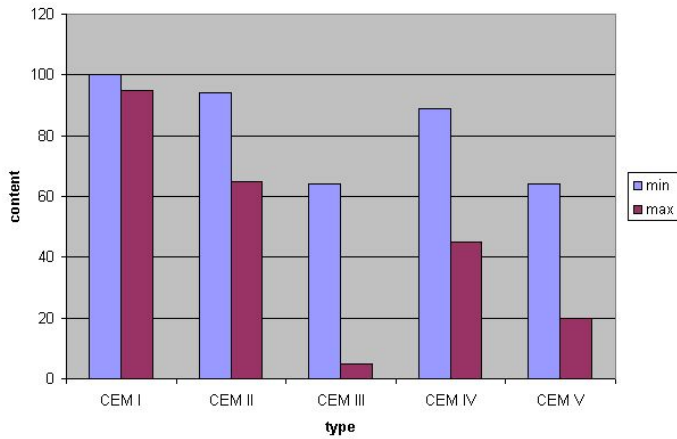
On average 50% is due to decarbonisation of limestone, which is an indispensable raw material for cement.

The rest (15%) are 'remote' emissions of CO₂, mainly being related to the consumption of electrical energy.

The total amount of CO₂ emitted is in between 400–1,000 kg/ton cement, depending on many parameters. Every part of it is subject to permanent reduction measures. So what can be done to lower the CO₂-emissions of the cement industry?

Given the above range there must be plenty of opportunities.

- The clinker burning and grinding process could be further optimised. Basically, this is ongoing business since decades.
- Fossil fuels could be replaced by non-fossil fuels or biomass. In the last decade European cement industries have made a real shift in this direction, while not increasing their emissions. Note that the energy efficiency of cement kilns clearly surpasses that of waste incinerators using best available technology.
- The clinker content of cement could be lowered by the use of puzzolans, fly-ash, limestone, shale, silica fume and blastfurnace slag. Basically these cements are known as blended cements. The success depends primarily on the local availability of resources.
- Electric power plants could use nuclear or hydro-energy.



Clinker content cement types (EN 197)

Worldwide Portland cement (CEM I) is the most used cement (clinker content 95-100%). For most environmentalists that is the benchmark, an unreliable benchmark as we will see. In Europe it is Portlandlimestone cement (CEM II; clinker content 65-94%) that is most sold, predominantly in Mediterranean countries. In the Netherlands it is blast-furnaceslag cement (CEM III/b; clinker content 20-34%).

In theory CO₂-emissions could even be below 400 kg/ton cement. In theory, because there are some other boundary conditions that are to be met. But the cement industry is working on a further reduction, together with partners in the value chain and with remarkable results.

2.2 Transport

The third source of CO₂ emissions throughout the value chain of concrete is transport. The amounts of cement and concrete that have to be put in place are quite serious. And not only of concrete and concrete products. The constituents also have to be mined, purchased and distributed.

All together building materials form a significant part of the freight load on Dutch roads (in total 375 Mt; building materials 132 Mt; concrete 40 Mt, CBS - 1998) and waterways (building materials: 54 Mt). The domestic transportation of (all) goods on roads causes 7% of the annual CO₂ emissions in the Netherlands. We may take into account that building materials are heavy most of the time, but not transported over long distances. The concrete market is predominantly a local or regional market. Economy of scale and logistics are often counteracting partners: the bigger the factory, the more efficient the production process, the more distant you can deliver your product, the more CO₂ you will emit, etc. There are no exact statistics on how much CO₂ is related to the transport of cement and concrete, at best some calculated estimations.

From the above, however, and from environmental databases on road transportation, it can be stated that the transportation of concrete adds up to about 10% of the embedded energy of concrete (on average).

The Netherlands is blessed with many waterways, which enable to transport a lot of raw materials and intermediates via rivers and canals in a relatively environmental way.

Industry continuously strives towards improvements, as a matter of fact, also when it comes to transportation.

2.3 Ready mixed concrete

From an environmental point of view the production of ready mixed concrete is first of all a logistical process; purchase and deliveries. A ready mixed concrete plant consists of storage of raw materials and cement, and of a mixing installation. Basically that's all there is. The art of making ready mixed concrete lies mainly in mix design. From the energetic viewpoint ready mix concrete installations are hardly interesting. They require only some electrical energy.



The ready mixed concrete industry takes the responsibility for the transport to the building site. As a consequence the majority of the people employed by this industry are truck drivers. The logistics of ready mix concrete deliveries is a matter of permanent attention. .

2.4 Concrete products

Embedded Energy

Concrete has to be cast in moulds in order to get the right shape either in a factory or on site. The moulds will contain some embedded energy. Structural concrete has to be reinforced. Reinforcement steel is a major contributor to the embedded energy of concrete. Per kg reinforcement bars contain seven times as much energy as cement! Pre-stressing of concrete leads to lean constructions and lower material use. At the same time the embedded energy per unit of mass seriously increases.



The same is more or less true for High Strength Concrete. Whether the net outcome of CO₂ is positive or negative depends on the situation. Dedicated LCA based computer programmes are helpful to calculate the CO₂ balance. Again, the mixing of concrete requires only little energy and so does the mould. Heating of the mix, in order to accelerate the curing, may be a factor. More in general, all measures to speed up the curing process cost extra energy, which may be earned back in an economical sense.

Thermal Mass

The total amount of embedded energy in residential buildings is very much case dependent. It is true: when the thermal mass increases, physical mass and embedded energy will increase too. The ratio between embedded energy of a building and the life time energy demand by a building varies from 20-80 until 100-0. Environmental life cycle analysis should help to find out where the minimum sum of the two lies.

It does make hardly any sense to put much focus on details as long as only little thought is spent on the lifespan of concrete. In many cases the (technical) durability of concrete is much longer than the economical lifespan of the construction it is used in.

A debate on the possible extension of the life spans, both technical and economical, might bring much more CO₂-savings than e.g. optimizing the mould in which the concrete is cast.

2.5 Short term costs; long term benefits

From a thermal point of view concrete has three interesting properties; it insulates, it has a good thermal capacity and it is heavy. The result is that your indoor climate, if your house is built in concrete, will be stable and comfortable, without excessive measures or heating/cooling costs.

You will always need a combination of insulation, thermal capacity and thermal mass to fulfil the requirements of a 'zero carbon house'.

Practically speaking most existing and new build dwellings still have a long way to go.

Today the operational costs of a building are highly determined by heating and cooling; by the use of energy. The amount of energy needed for a life span heating and cooling of a building quickly exceeds the embedded energy of the whole building.

Thermal mass reduces heating energy consumption of a building by up to 15%. Thermal mass is not only in the floors and walls inside a building, but can also be found in concrete foundation piles, which are specially designed for storage of heat and cold.

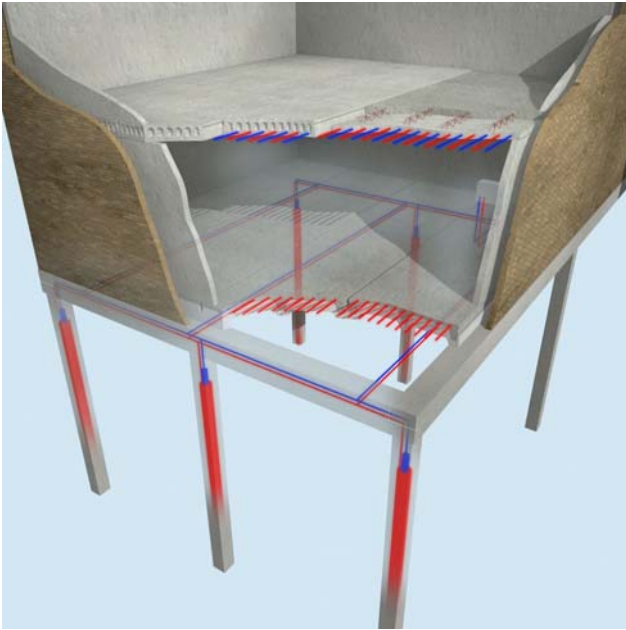
Thermal mass also reduces the need for cooling capacity. Peaks in temperatures come delayed and are considerably squeezed down before they enter a building. When combined with air-conditioning it may reduce the energy used for cooling by up to about 50%.



These are impressive numbers. Once more if we remember that even in moderate zones heating and cooling of buildings consumes more than 30% of

all fossil fuels. That is at least ten times as much as the cement industry does.

Concrete floors, walls and foundations can all be used as storage for heat or cold.



There is another aspect of concrete that has to be mentioned: carbonation. Carbonation is a chemical process where atmospheric CO_2 reacts with CaO in concrete to form CaCO_3 , calcium carbonate.

On the one hand civil engineers try to slow down this process which takes place on the surface of concrete, because it could lead to the corrosion of the steel bars in reinforced concrete. On the other hand environmentalists would encourage carbonation. The good news is that carbonation especially takes place after the use phase of concrete: when the concrete is crushed to aggregates. Accelerated small scale laboratory tests in Nordic countries have shown that after a period of 100 years pretty much (22-26%) of the de-carbonated cement has been re-carbonated again, depending on a huge variety of parameters.

The relevance of this phenomenon for the CO_2 -balance of the earth is unclear, but the phenomenon takes place every day.

2.6 Reuse

By far the best ways to save energy are life time extension and reuse. Concrete structures are durable and can be used in second life. There are marvellous examples! The benefit of these options overrules nearly every environmental choice you can make in concrete mix design or structural engineering.

Yet not every structure complies with contemporary requirements and has to be demolished one day.

2.7 Recycling

Basically recycling of concrete can take place in five different ways.

- as recyclable parts
- as crushed demolition waste
- as crushed concrete in road building
- as crushed concrete in new concrete
- split-up in the original constituents

From an environmental point of view these alternatives may have different impacts. It is hard to say in general terms which option is best.

The impact should also be weighted against the impact that can be prevented by not using virgin materials and not bringing waste to landfills. NIBE (Dutch Institute for Building Biology and Ecology) calculated that a 100% replacement of coarse aggregates by crushed concrete may lead to an overall environmental benefit of 6-7%.

As the embedded energy in concrete is relatively low, it makes hardly any sense to recycle in a way you would do with scrap metal. Crushing, sorting and sieving are all you can reasonably do. Crushing of concrete may accelerate the carbonation process, with subsequent positive effects on the carbon footprint.

The last option, split-up concrete in its original constituents, may seem rather odd. The Dutch TNO Kringbouw-project has shown, however, that it is possible to grind used concrete in such a way that there is a cement-rich fraction and an aggregate rich-fraction.

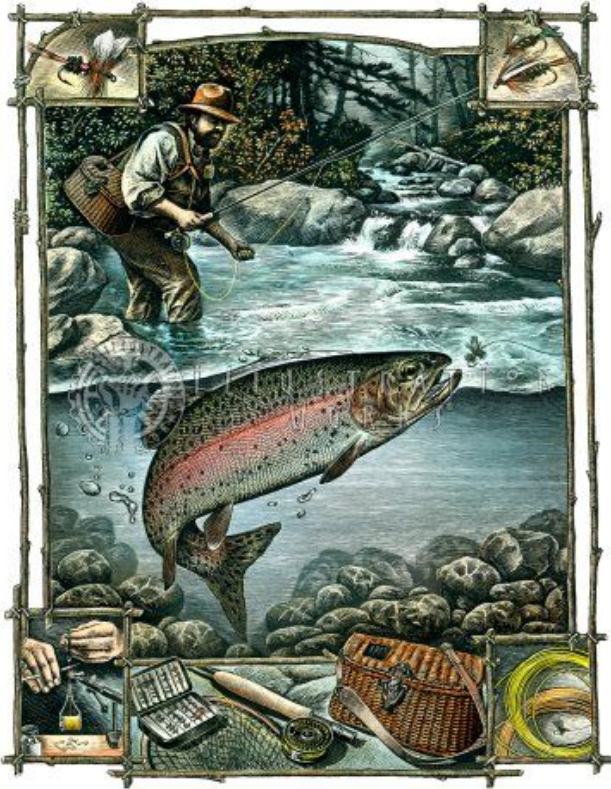
The cement-rich fraction has some residual binding capacity and besides it is rich on calcium-carbonate, the raw material for cement production. Calculations on CO_2 show that both recycling as a secondary binder and as raw material make sense.

3 CONCLUSIONS

Carbon dioxide is governing today's political agenda. This policy also influences upon the construction industry. Two thirds of the Dutch concrete production ends up in housing and non-residential buildings, both sectors where energy saving is a top priority. More than one third of the national energy demand goes into heating and cooling of buildings. Given these facts there is a strong demand to assess the carbon footprint of concrete and the energy saving potential of building with concrete in a balanced way.

The over-all assessment can be summarized by a well-known English expression:

“You must lose a fly to catch a trout”



Yes, the production process of concrete constituents leads to emissions of carbon dioxide, which can and will be further reduced. The application of concrete is often a good alternative to other materials in terms of embedded energy, durability and financial performance.

In a significant number of cases, concrete saves a substantial amount of energy in the use phase. Carbon Neutral Concrete is probably closer by than you thought it was.

“It’s no good weeping about a fly once you have caught a trout”.

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