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British Precast
Drainage Association

Publications from the British Precast Drainage Association (BPDA):

BPDA was formed in 2017 from the integration of the Concrete Pipeline Systems Association (CPSA) and the Box Culvert Association (BCA).

Information published by both CPSA and BCA will be rebranded and replaced as BPDA in due course. New material will be branded BPDA.

All CPSA and BCA web traffic will be redirected to the new BPDA web site at www.precastdrainage.co.uk

Carbonation (Part 1) – How it reduces the carbon footprint of concrete

Concrete carbonation is the reaction between carbon dioxide with the alkaline components of hardened concrete (CaO) to form Calcium Carbonates ($CaCO_3$).The process turns concrete into a carbon sink and can play a major part in reducing atmospheric carbon dioxide.The amount of CO_2 absorbed can effectively reduce the cradle-to-gate carbon footprint of a concrete element and in the case of concrete pipes, by around ***10%****. The carbon emissions of concrete pipes can therefore look markedly different if such factors are included in the carbon auditing process.*

Understanding Carbonation

Carbonation can occur in virtually all concrete elements produced using Portland cement (CEM I). When limestone is calcinated during the manufacture of Portland cement, calcium carbonate components are broken down, releasing carbon dioxide. Calcination contributes between 50 to 70% of the carbon footprint of Portland cement (CEM I). Research indicates that hardened concrete can bind approximately the same amount of CO_2 during carbonation, where calcium hydroxide is converted to calcium carbonate and water.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

The process of total carbonation happens over a very long period which might extend to tens, hundreds or even thousands of years. However, the two main peaks in terms of carbonation rate take place in the first year and immediately after the concrete crushing process (after life).

Carbonation is not always taken as a benefit. It can have a detrimental impact where steel reinforcement can lose its protection from the usual high alkalinity of concrete and may start to corrode, leading to expansion of the steel and spalling of the concrete at the surface. Structural concrete is designed to minimise the depth of carbonation over its design life and reinforcement is positioned at a cover depth greater than the anticipated depth of carbonation. However, carbonation can also offer a protective layer at the surface of a concrete element that makes it less susceptible to chemical attack, including sulfates (BRE SD1, 2005). The process of autogenous healing is also a characteristic of concrete, where absorbtion of CO_2 can lead to the deposition of calcium carbonate and sealing of cracks.

How much carbon is absorbed

Concrete will carbonate wherever there is exposure to carbon dioxide, but the rate and speed of carbonation will depend on a number of factors:

- **Length of exposure to air:** CO_2 absorbed increases with time with most absorption happening during the first year. Research from the US, Scandinavia and a number of other countries proved that the rate of carbonation can decrease rapidly over time and that most of the carbonation would take place during the first 50 years.
- **Concrete exposure:** Research by PCA in the US demonstrated that carbonation can reach a depth of 18mm. Research in the UK shows that up to 25mm can be affected. A default thickness of 23.3mm is taken for the UK (Clear & De Saulles, 2007). A study carried out by SCCI (Lagerblad, 2006) proved a strong link between the status of a concrete surface (buried, exposed, sheltered, indoors) and levels of carbonation. The shape of a concrete pipe should theoretically ensure maximum exposure (per mass). However, the position of a concrete pipe (buried) will affect its lifetime absorption levels of CO_2.
- **Type of Concrete:** The SCCI study demonstrates that strength and grade of concrete will affect its susceptibility to carbonation.
- **Concrete mix:** Nordic research argues that some CEM II cements (e.g. Portland cement blended with GGBS or silica fume) leads to higher carbonation rates than a CEM I based mix with an equivalent

strength. A BRE report notes that an increase of 10% in carbonation rate should be proposed for fly ash blended cement, which is typical for precast concrete pipes and manholes.

The following diagram is from the SCCI study: It shows the proportion of CO_2 emitted and absorbed throughout the service life and after life of a concrete product.

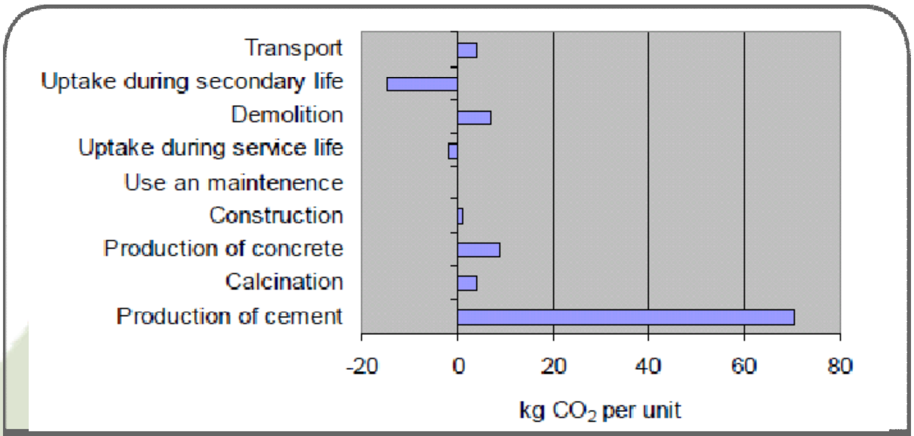

Figure 1. CO2 absorption (kg) per unit of concrete (SCCI, 2006)

Due to the difficulty in calculating carbonation values specifically for concrete pipes based on available literature, calculations were carried out using two separate references: Calculation for service life carbonation were based on work by Clear & De Saulles (2007), and calculations for end-of-life carbonation was based on findings of an EUPAVE publication.

Calculating Carbonation for Service Life

The following equation was originally developed for BRE based on the SCCI research and was later modified by Clear & De Saulles (2007):

$$\mathbf{M = K \times S \times L^{0.5} \times Q \times 0.65 \times (44/56) \times C \times E}$$

Where

M = Mass of CO_2 (kg)

K = Specific recarbonation rate for concrete (mm/year$^{0.5}$)

S = Surface area of concrete element (m^2)

L = Service Life of concrete element (years)

Q = Quantity of CEM I component per m^3 of concrete (kg)

C = Ratio of CaO reacting with CO_2 to form $CaCO_3$

Secondary Life Carbonation Factor (E) was removed from the equation.

For a one metre length of DN450 concrete pipe, 10% was added due to the fly ash content, as recommended by BRE, and a 0.5 ratio is assumed for CaO reacting with atmospheric carbon dioxide. The mass of atmospheric CO_2 absorbed (M) in kg therefore equals:

$$0.00075 \times (3.14 \times 0.45 \times 1) \times 10 \times 252 \times 0.65 \times (44/56) \times 0.5 \times 1.1 = \mathbf{0.75\ kg\ CO_2}$$

Calculating after life Carbonation

Crushing of concrete exposes more surface area to the atmosphere and can lead to an increase in carbonation: EUPAVEĉs ña Smart and Sustainable Choiceò 2009 publication refers to research showing that the amount of absorbed carbon dioxide is between **15 to 35 kg CO_2e/m^3** of concrete rubble over 2 to 3 years: **25 kg CO_2e/m^3** is therefore taken as a conservative estimate.

For a DN450 pipe the amount of CO_2e absorbed by the concrete rubble is **2.98 kg CO_2e/ m.**

This represents 3.73 kg CO_2e/ m service life plus after life absorbtion, or a 9% reduction to the cradle-to-gate carbon footprint. It demonstrates that the carbon footprint of concrete on a cradle-to-gate or cradle-to-site basis may not offer a truly representative view on the net effects of greenhouse gas emissions. When the emissions from crushing of pipes are included, the overall effect is still negative. A more reliable assessment is to include the carbon dioxide absorbed via carbonation. The new ISO 15804 standard for Environmental Product Declarations and category rules for construction products should allow for some of the impacts associated with end-of-life carbonation to be inlcuded in carbon footprints, although not as an integral part of the embodied carbon calculation[1].

Impact on concrete pipes

The table below shows the cradle-to-gate carbon footprints of concrete pipes when service life and after life carbonation is taken into consideration. The net impact should be considered when making comparisons with alternative pipeline materials.

Concrete Pipe	Carbon Footprint (kg CO_2e/m)	Service life carbonation (kg CO_2/m)	EUPAVE after life (kg CO_2/m)	TOTAL Carbonation (kg CO_2/m)	Change to carbon footprint (%)	Impacts of crushing (kg CO_2/m)	Net Carbon Emissions (kg CO_2/m)
DN225	16.36	ï 0.38	ï 1.23	ï 1.61	ï 9.8%	1.07	15.82
DN300	25.63	ï 0.50	ï 1.82	ï 2.32	ï 9%	1.43	24.74
DN450	42.07	ï 0.75	ï 2.98	ï 3.73	ï 8.9%	2.07	40.41
DN600	72.00	ï 1.00	ï 5.1	ï 6.10	ï 8.5%	2.77	68.67
DN750	106.75	ï 1.25	ï 7.16	ï 8.41	ï 7.9%	3.35	101.69
DN900	131.79	ï 1.50	ï 8.36	ï 9.86	ï 7.5%	4.00	125.93
DN1050	175.30	ï 1.75	ï 11.2	ï 12.95	ï 7.4%	4.67	167.02
DN1200	223.80	ï 2.00	ï 14.59	ï 16.59	ï 7.4%	5.33	212.54
DN1350	273.54	ï 2.25	ï 18.75	ï 21.00	ï 7.7%	6.00	258.54
DN1500	341.40	ï 2.50	ï 22.04	ï 24.54	ï 7.2%	6.69	323.55
DN1800	457.37	ï 3.00	ï 29.89	ï 32.89	ï 7.2%	7.99	432.47
DN2100	559.04	ï 3.50	ï 36.93	ï 40.43	ï 7.2%	9.09	527.7

References

- **BRE** (2005) BRE Special Digest 1: 2005 *Concrete in aggressive ground*.
- **Gajda**, J (2006) *Absorption of atmospheric carbon dioxide by portland cement concrete*. PCA R&D Serial No. 2255a. © Portland Cement Association
- **Lagerblad**, B (2006) *Carbon dioxide uptake during concrete life cycle.* Nordic Innovation Centre.
- **Clear**, C; **De Saulles**, T (2007) *BCA Recarbonation Scoping Study*. BCA, 2007.
- **CPSA, Carbon Clear,** (2010) Partial Cradle-to-Gate Life Cycle Analysis of precast concrete pipes, manhole rings and cover slabs

For further information please contact your usual supplier

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[1] The carbon emissions arising from pipe exhumation were not taken into consideration. It is assumed that this will not affect the relative difference between alternative pipes materials.