CONCRETE FUTURES

Spring 2023

mpa The Concrete Centre

All change: concrete in an age of transition

The innovations and technologies driving us to net-zero and beyond

THE CAPTURE
SCALING UP CCUS – THE BIGGEST WEAPON IN THE WAR ON CARBON

THE FORMULA
THE MULTI-COMPONENT CEMENTS THAT CAN MAKE AN IMPACT NOW

THE AFTERLIFE
HOW WE CAN ACCELERATE CARBONATION TO ABSORB CO_2

Carbon featherweight

The Featherstone Building near Old Street is developer Derwent London's latest take on the smart, sustainable workplace. Like the nearby White Collar Factory, concrete is to the fore: low-carbon mixes include 70% GGBS in the foundations, 50% in the cores and columns and 30% in the slabs, which also incorporate active cooling. The building, designed by Morris + Company, is targeting a BREEAM Outstanding rating. Look out for more in-depth coverage of the project in the spring issue of Concrete Quarterly.

Photo: Jack Hobhouse

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The Concrete Centre

The Concrete Centre provides design guidance, seminars, courses, online resources and industry research to the design community. Our aim is to enable all those involved in the design, use and performance of concrete to realise the potential of the material.

The Concrete Centre is part of the Mineral Products Association, the trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries.
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Edited and produced by Wordmule **wordmule.co.uk**
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Cover: Farringdon Elizabeth Line Station, London (see page 10).
Photo by Morley von Sternberg

WELCOME

As is often noted, concrete is a ubiquitous construction material across the world, essential for structures that protect us from the elements and for the networks that deliver power, water, sanitation and transport. Its inherent resilience means that it will continue to play a vital role in buildings and infrastructure in a changing climate, both in its primary use and as a recycled material (pages 14-19).

That's the long term. In the short term, it is essential that we reduce the carbon impacts associated with concrete, to reach the goal of a net-zero built environment by 2050. Since the UK concrete industry launched its sustainability strategy in 2008, the embodied carbon of a tonne of concrete has fallen by 30% against a 1990 baseline. Later this year, it will publish a revised strategy, setting targets for the next leg of our decarbonisation journey, as well as incorporating goals for biodiversity, social value and a circular economy.

Right now, a key strategy for reducing concrete's embodied carbon involves replacing a proportion of cement content with industrial by-products, using up materials that might otherwise go to waste. This is one of the technologies playing a part in the transition to net-zero, while more permanent solutions, such as carbon capture (pages 4-9), are under development.

THESE MULTI-COMPONENT BLENDS HAVE THE POTENTIAL TO BECOME THE DEFAULT OPTION FOR ALMOST ALL OF THE CONCRETE POURED IN THE UK

As stocks of these materials fall, new constituents are becoming available: an incoming revision to the British Standard for concrete, BS 8500, will allow specifiers to call on a new generation of low-carbon mixes based on the UK's abundant supply of limestone (pages 10-13). These multi-component blends have the potential to be delivered at scale, and to become the default option for almost all of the concrete poured in the UK today.

The introduction of such mixes may be just one of many small steps that will take us to net-zero and beyond, but it is a welcome example of what real, sustainable change looks like.

Claire Ackerman, executive director, The Concrete Centre

THE CAPTURE

With the UK's first carbon capture cement plant due to open in 2027, the time is ripe for this game-changing technology. Tony Whitehead reports

Since 1990, the UK cement and concrete industry has reduced the carbon it emits by more than half. But to go further, and to reach its goal of net-zero emissions by 2050, the industry will require game-changing new technology: CCUS, or carbon capture, utilisation and storage.

"When it comes to tackling that remaining 50%, CCUS will probably be the single biggest contributor," says Dr Diana Casey, director of energy and climate change at the Mineral Products Association (MPA). "The UK concrete and cement industry Roadmap to Beyond Net Zero shows that we expect CCUS to account for some 60% of the reductions we still need to achieve."

So far, carbon emissions have been reduced mainly by using alternative, non-fossil fuels such as waste biomass to heat cement kilns, and by increasing cement replacements such as ground granulated blast-furnace slag (GGBS) or fly ash in concrete, she explains. "There is still some scope to use these and other innovations, such as greener

transport, to improve further, but we have already exploited much of their potential. The nature of cement production, particularly Portland cement, means that fuel switching and other efficiencies can never completely eliminate all CO_2 emissions."

Carbon emissions from cement production derive from two main sources. Around one-third arises from burning the fuel needed to heat cement kilns to the required 1,450°C, but the majority is emitted from the chemical breakdown of raw materials at those high temperatures: the calcination reaction that breaks limestone (calcium carbonate) down into calcium oxide.

"These chemical process emissions currently account for 60-70% of the carbon associated with UK cement production," says Casey. "We can reduce these by using replacements like slag and fly ash, but the only way to eliminate them is through carbon capture."

Though the technology has existed since the 1970s, globally there are currently fewer than 40 commercial carbon capture plants, and many of these are demonstrator-scale projects. But the picture is changing rapidly. In the UK, the first carbon capture cement plant planned for Hanson's Padeswood site is expected to be up and running by 2027 (see box, overleaf). Around the world, members of the Global Cement and Concrete Association have more than 35 projects announced or underway, according to Claude Lorea, GCCA director of cement. "Though, as yet, there is only one commercial-scale plant actually being constructed, in Norway, we expect there to be ten such plants operational by 2030," she says. "Hundreds more are in the pipeline, with news of a new project almost every week."

But installing carbon capture technology at cement plants is only one part of the equation. Captured gas has to be compressed and transported to a place of use or permanent geological storage such as a depleted gas field. This will require considerable new infrastructure, including pipelines to transport the gas from the plant to where it will be stored. "Our industry is eager to progress, but the infrastructure requirements necessarily involve governments," adds Lorea. "We can't do it alone."

Left and below: Heidelberg Materials' carbon capture plant in Brevik, Norway, will be the first such facility to be installed at a cement works. It is due to be operational by autumn 2024

HUNDREDS MORE COMMERCIAL-SCALE PLANTS ARE IN THE PIPELINE, WITH NEWS OF A NEW PROJECT ALMOST EVERY WEEK

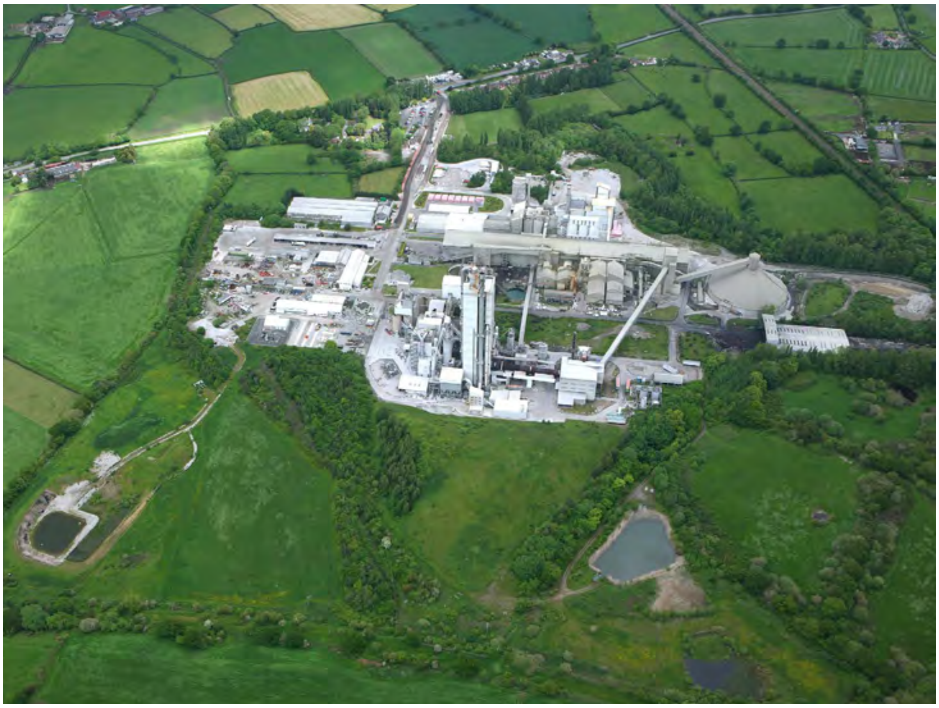
Another consideration is cost. CCUS is expensive, with the MPA estimating that the capital cost of adding CCUS to a cement plant is roughly the same as that of constructing the cement plant itself. Costs are expected to reduce as the technology becomes more established – or improved through innovation.

This is one reason that the GCCA has launched two innovation platforms. The first is the Innovandi Network, a consortium of 40 universities and 34 industrial partners committed to supporting independent research. It also runs the Innovandi Open Challenge. ▶

Photos: Heidelberg Materials / Dag Jenssen

CAPTURE **FROM CEMENT**

Padeswood seizes the moment



The world's first cement plant to be fitted with industrial-scale carbon capture technology is currently under construction at Brevik in Norway. The second – and the UK's first – is likely to be Hanson's Padeswood plant in Flintshire, north Wales.

"We are neck-and-neck with another Heidelberg Materials project in Edmonton, Canada," says Iain Walpole, Hanson's head of process and sustainability for carbon capture. "But it doesn't matter who comes second. We just want to start capturing CO_2 at our plant as soon as we can."

Subject to necessary consents and government funding, Hanson hopes to start construction of the new carbon capture plant in 2024. So how will it work?

Walpole says that Padeswood, which opened in 1949, is fairly typical of the dozen or so major cement manufacturing plants in operation in the UK. Its kiln is a state-of-the-art five-stage precalciner, and it currently represents about 10% of UK cement production. The carbon capture unit will be built next to the existing plant, covering a similar footprint to the kiln line. It is set to cost around £400m to construct, and will capture some 800,000 tonnes of CO_2 annually.

Padeswood will use the most mature and proven technology, based on amine, an organic solvent derived from ammonia. This involves circulating the flue gases through an 80m-high absorber column, where the CO_2 bonds with the amine. This prevents 95% of the CO_2 in the exhaust gases from escaping into the atmosphere. CO_2-rich amines are then pumped to a regenerator column and boiled to release near pure CO_2, which is then compressed and purified before being piped away from the site.

THE NET FIGURE COULD BE AROUND -200KG OF CO_2 FOR EVERY 100 TONNES OF CEMENT PRODUCED

Carbon capture is an energy-intensive process, says Walpole. "Our gases start out at 120°C, but have to be cooled to 40°C – the optimal temperature for amine to do its work. Then the amine has to be reboiled at 120°C to release the CO_2, and after that, cooled again so it can be reused. Around 1,000 tonnes of amine solvent needs to be circulated every hour to capture 100 tonnes of CO_2."

Walpole says that the carbon capture plant will use as much energy to capture 1 tonne of CO_2 as the cement consumes to produce 1 tonne of cement: "Roughly 85% of the extra energy is used to heat and cool the amines, and around 15% is electricity needed to power pumps, fans and compressors."

This will be supplied by a dedicated combined heat and power (CHP) unit, which will be powered by natural gas, with its exhausts fed through the carbon capture stack too. "To minimise the heat demand from the CHP, we plan to use waste heat from the cement plant for about 20% of our amine heating requirement," says Walpole.

He adds that the cement produced at the plant could be carbon negative: "Although the technology only captures 95% of the CO_2 we produce, some of this comes from biofuels which are already classed as zero-carbon. The net figure could be around -200kg of CO_2 for every 100 tonnes of cement produced."

Once captured and compressed, the CO_2 will be taken via a dedicated new 10km, 16" diameter pipeline to connect to HyNet's 36" diameter pipe, which will collect CO_2 from the entire HyNet area (see main copy). This will then link to a repurposed natural gas pipeline that will take the CO_2 for permanent storage 1km below the seabed of Liverpool Bay in the Irish Sea.

"This was established to help start-up companies with great new ideas on how to improve our industry, including on carbon capture," explains Lorea. "Our accelerator programme gives them direct access to academic advice, along with the labs and know-how of our members."

Among the participants is Carbon OrO, which is exploring the potential of biphasic amines to make carbon capture more efficient. These can save energy by absorbing and releasing CO_2 at lower temperatures than traditional amine solvents. On a different tack, Carbon BioCapture is using algae to capture CO_2 directly from industrial waste gases; the algae, which thrive on CO_2, can then be sold as agricultural feedstuff. Fortera's technology, meanwhile, combines CO_2 emitted from cement plants with calcium oxide to make reactive calcium carbonate; Carbon Upcycling uses a low-energy process to chemically activate and capture CO_2 within solid waste to produce supplementary cementitious materials; and MOF Technologies has harnessed a new class of solid sorbents called metal-organic frameworks in a filtration system that removes CO_2 from flue gas using pressure rather than heat, reducing the energy required by up to 80%.

"There's a huge amount of real innovation happening – but realistically it will take time for costs to fall," says Casey. In the meantime, government will need to step in to ensure UK producers can compete on a level playing field: "Costs cannot currently be passed on to customers, because they will simply buy cheap, higher-carbon imports instead," she points out.

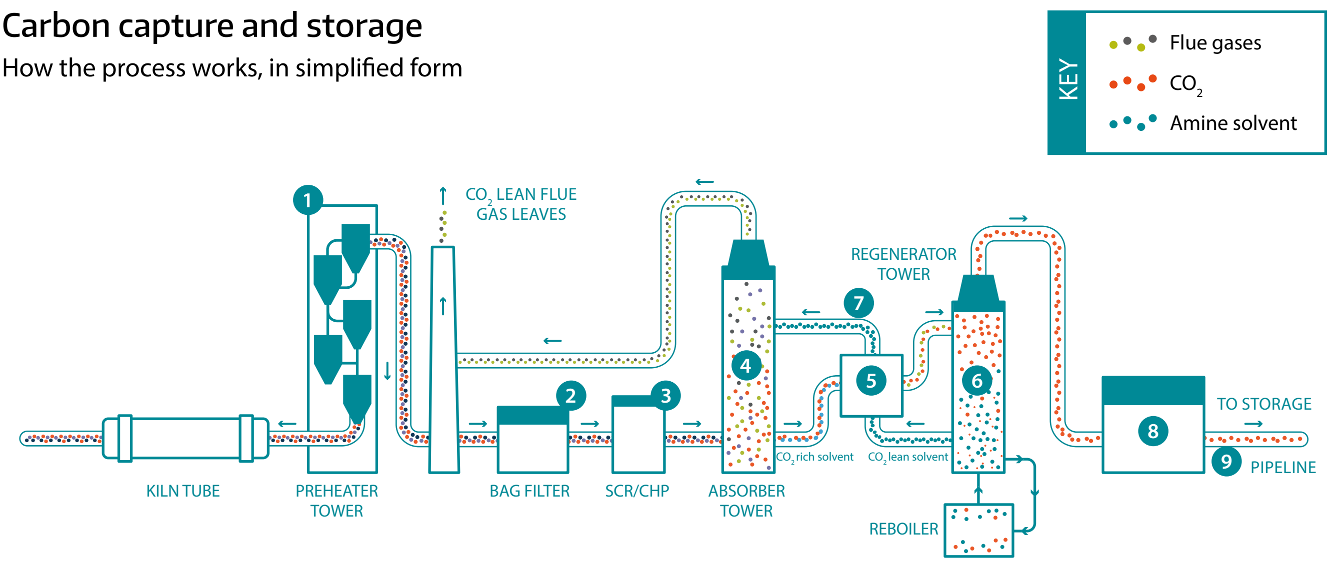
The UK government is aware of these challenges and is starting to address them. Understanding that CCUS cannot operate in isolation, it is taking forward the technology in two initial "clusters", areas where carbon capture plants can be joined to a new network of pipelines to transport compressed CO_2 from a range of sources to permanent storage destinations off the coast of Britain. The clusters already announced are in north-east England and around Manchester, Liverpool and Cheshire. Known as HyNet, this latter cluster will collect CO_2 from new hydrogen production plants, the petrochemical industry in the Ellesmere Port region, and Padeswood (see opposite).

David Parkin is director of Progressive Energy, HyNet's originator and project coordinator. "HyNet is sized to collect about 10 million tonnes of CO_2 per year," he says. "About half of this will come from new plants producing hydrogen from natural gas, with the rest coming from large industrial contributors such as Padeswood. The CO_2 will be stored under the Irish Sea in depleted gas fields which are coming to the end of their useful lives. We can repurpose the reservoirs, the platforms and the pipelines which now bring gas to shore, to send back CO_2 to permanent storage beneath the seabed."

The existing pipeline effectively stops at Connah's Quay in Flintshire, so HyNet plans to build a 35km extension to enable CO_2 to be collected from Stanlow ▶

Carbon capture and storage

How the process works, in simplified form



1. Preheater tower, where cement raw materials are heated to 900°C
2. Bag filter dust from the kiln system removed from the gas flow
3. Flue gases from the kiln are cleaned in the selective catalytic reduction plant (SCR). Heat and electricity needed to operate the capture plant is produced in the combined heat and power plant (CHP)
4. CO_2 is collected from the flue gases as it reacts with the amine solvent
5. Heat exchanger
6. CO_2 stripped from the amine solvent
7. Lean amine solvent is returned to absorber tower
8. CO_2 is then compressed
9. CO_2 sent via pipeline to permanent storage

Photo and diagram: Hanson

CAPTURE **IN CONCRETE**

The perfect hiding place

The majority of the CO_2 removed by new carbon capture technology is likely to be stored underground. But there is also another destination: concrete itself.

"All concrete naturally absorbs CO_2 from the air through the process of carbonation," explains Elaine Toogood, The Concrete Centre's director of architecture and sustainable design. The process is well understood, but exactly how much, and at what stage of its life, is harder to say, as it depends on variables such as density and location. However, it is believed that up to one-third of concrete's carbon footprint can be reabsorbed during its lifetime (see pages 14-19). "What's exciting is that by subtly adjusting the chemistry of concrete-making, we are learning both how to accelerate this process, and how to persuade concrete to permanently store more CO_2 – potentially even more than it took to make."

Some of this technology is quite established. CarbonCure, founded in the US, injects captured CO_2 directly into concrete while it is being mixed. Applicable to both precast and ready mix, it says this permanently stores 15kg of CO_2 per m^3, and has been deployed in projects across the US, including the new Amazon headquarters in Washington DC. In addition, CO_2 can be added to wastewater from the batching plant where it is absorbed into residue, making it suitable for adding to new concrete mixes. In the UK, Marshalls Group is using CarbonCure's technology to make concrete bricks with waste CO_2 from the fertilizer industry. Marshalls estimates that its pilot project will permanently remove approximately 30 tonnes of CO_2 every year.

Another US firm, CarbonBuilt, has taken a different approach. It adds hydrated lime to its mix to help it absorb CO_2 more quickly. Precast products such as blocks can then be cured in containers filled with CO_2 taken directly from flue gas to produce a product with a claimed carbon footprint reduction of 60%. A variation on this is a non-hydraulic, low-calcium cement formulated by Solidia. CO_2 is again absorbed into precast products during the curing process – with the added benefit of faster curing.

CO_2 can also be used to mineralise various industrial wastes such as air pollution control residues. In the UK, Carbon8 and OCO are using this technology to make carbon-negative aggregates which could in turn be used to make low-carbon concrete. "These aggregates are usually lightweight, so the concrete can reduce loading," says Toogood.

Also in the UK, Seratech has developed a process involving olivine, an abundant mineral comprising mainly magnesium silicate. By adding CO_2, Seratech's technology produces two compounds: a silica powder that can be used as a supplementary cementitious material (SCM) to make concrete, while the CO_2 ends up permanently stored within a magnesium carbonate by-product suitable for making bricks. The company says that its engineered silica SCM need replace only 35% of the Portland cement content to produce carbon-neutral concrete.

Other promising research is focusing on how to sequester more CO_2 as part of the concrete recycling process. Hanson recently announced a "carbon capture breakthrough" in its use of recycled concrete paste (RCP) in the wet scrubber of its Ribblesdale cement plant in Lancashire. In under 30 minutes, 15 tonnes of RCP was able to capture 1.5 tonnes of CO_2 from the plant's flue emissions. This carbonated RCP is potentially suitable to replace limestone in cement production.

Meanwhile, in France, the FastCarb project is looking at how to accelerate carbonation of recycled concrete – a process that, as well as using captured CO_2, also improves aggregate quality and its potential for use in concrete.

"With all these innovations, the carbon is used within the chemistry of the concrete or by-product," says Toogood. "This means that, unlike biogenic sequestration, the carbon is permanent stored. Even if the concrete is eventually crushed and buried, the carbon stays locked away for ever. These industrial carbonation technologies help add value to waste products, and could be a cost-effective way to reduce the amount of CO_2 that would need to be in undersea storage."

Photos: AKT II; Solidia

oil refinery and the hydrogen plants planned for that site. Subject to the necessary government approvals, work could start early in 2024.

Padeswood will require a dedicated smaller pipeline of its own to connect to HyNet's newly built one. This will be about 10km long and relatively straightforward, being mainly across open country. "Padeswood is the only cement plant in our area, so there is obviously an issue with other cement plants unable to connect to a CO_2 pipeline," says Parkin.

More clusters are planned – in Aberdeenshire, South Wales and Southampton, with some of these likely to be announced as "track two" projects later this year. But although these regions will involve several cement plants, others will remain outside the clusters and their vital CO_2 pipeline networks.

"Eventually, as we get closer to 2050, all cement plants will have to capture carbon," says Parkin. "Clearly that is a concern for these so-called 'dispersed sites' located outside planned clusters."

Moving a dispersed cement plant to an industrial cluster is usually impractical because they are located close to their raw material supply: limestone quarries. If you move the plant, you would have to truck the limestone; if you don't, you have to transport

Above left: AKT II's Crinkle Crankle Concrete installation at the 2022 London Design Festival. The wall and seat include blocks that use Seratech's cement-replacement technology, which permanently stores CO_2 within a magnesium carbonate by-product

Left: Solidia's non-hydraulic, low-calcium cement absorbs CO_2 into precast products during the curing process, shortening curing times. The CO_2 is locked away permanently in the form of calcium carbonate

WE CAN REPURPOSE THE RESERVOIRS, THE PLATFORMS AND THE PIPELINES WHICH NOW BRING GAS TO SHORE, TO SEND BACK CO_2

the CO_2, which ideally requires a pipeline as trucks are impractical for the volumes involved. "The sector needs the government to provide more guidance on how it intends to deal with dispersed sites and a plan for CO_2 transport infrastructure," says Casey. "It is difficult for our industry to make investment decisions around carbon capture without some visibility as to future policy."

She highlights other issues too: "Building carbon capture plants and infrastructure is a considerable technological challenge and requires a range of specialist skills. We are hoping for government involvement in attracting those skills to the UK and helping with the necessary training and education. The authorities themselves will also need to operate a clear and rapid permit system if the industry is to take carbon capture forward at pace."

Carbon capture is clearly a significant technological change, not only for the cement industry but for many other branches of manufacturing. It requires new skills, new regulations and new policies, as well as new plant, pipeline and storage networks. The UK cement and concrete industry has a proven record of innovation and has made a commitment to a zero-carbon future. But it can't do it alone. ●

THE FORMULA

A new generation of multi-component cements has the potential to substantially lower the embodied carbon of most of the concrete poured in the UK. And there are more innovations to come …

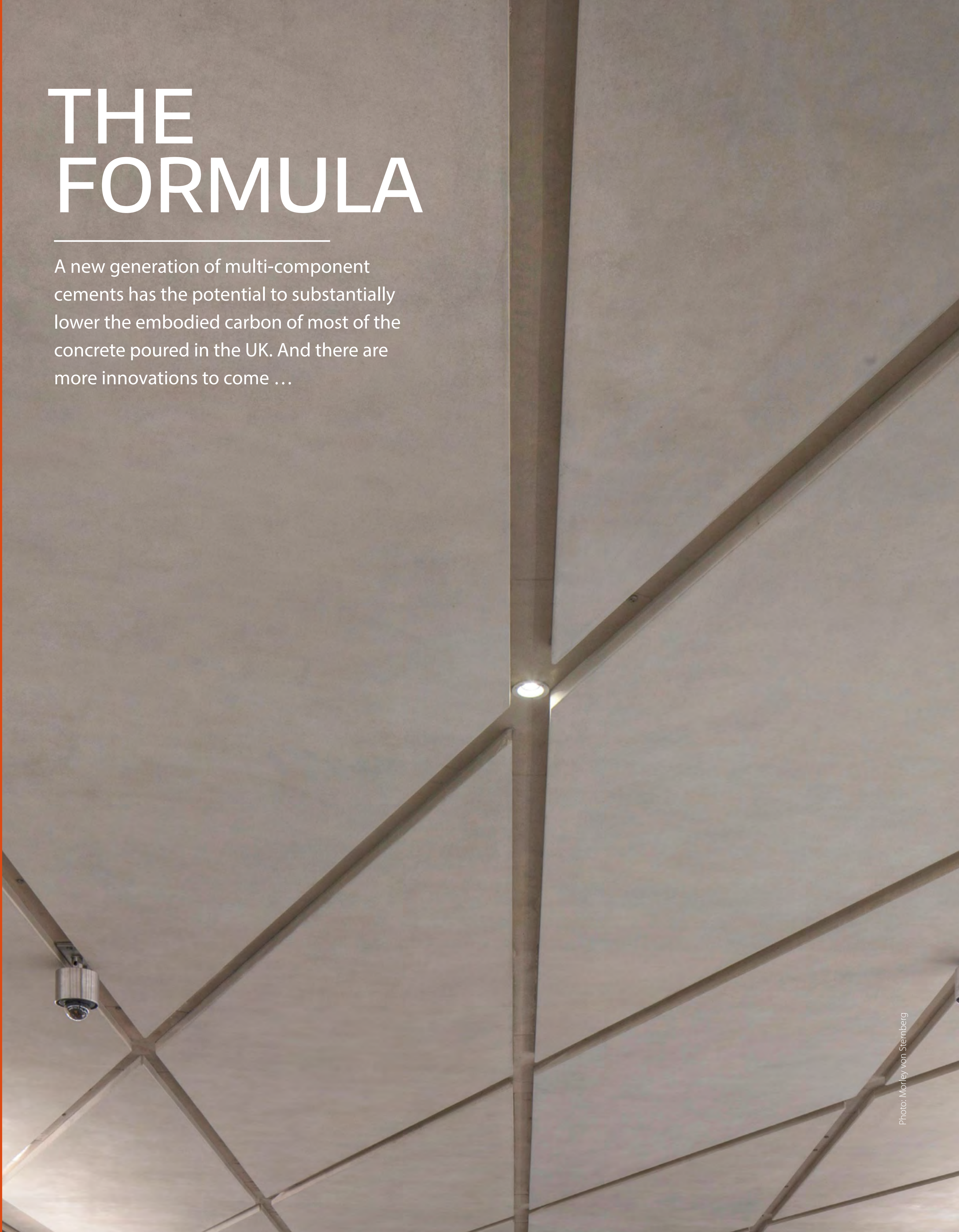


Photo: Morley von Sternberg

Later this year, a change in the British standard for concrete, BS 8500, will make a considerably wider range of low-carbon mixes available to designers, specifiers and contractors. These new-generation blends are based on general purpose cements, so they can be used in nearly all applications – which means their implementation will reduce the embodied carbon of most of the concrete specified in the UK.

Innovation in concrete mix design is part of the UK concrete and cement industry's Roadmap to Beyond Net Zero, and the revised standard is the result of substantial investment in research and testing. As well as adding to the list of low-carbon concretes available for use today, it also makes it easier for new products to be introduced in future, which should help accelerate progress too.

CEM I consists mostly of Portland cement clinker, which is relatively high in embodied carbon – it is concrete's cement content that is principally responsible for its carbon footprint. To reduce this, Portland cement is commonly blended with supplementary cementitious materials (SCMs), such as fly ash, ground granulated blast-furnace slag (GGBS) and finely ground limestone.

The UK has traditionally produced cements with a maximum of one secondary component. But research by the Mineral Products Association (MPA) has demonstrated the benefits of multi-component blends, particularly when limestone powder is used in combination with GGBS, fly ash or calcined clay. This, supported by proven use of multi-component cements and concretes in other countries including Ireland, has informed the forthcoming update to BS 8500.

Limestone powder is abundant in the UK. However, due to its limited chemical activity it is used to substitute clinker in lower quantities than fly ash or GGBS. The MPA research demonstrated that this issue can be overcome by using limestone powder alongside other, more reactive, constituents. Making use of limestone in multi-component cements will reduce demand for fly ash and GGBS without compromising performance, and help these valuable but finite materials to go further while longer-term solutions for decarbonisation are under development. Embodied carbon may be further lowered through optimised grinding and blending of the materials.

IF MULTI-COMPONENT CEMENTS WERE DEPLOYED TO THEIR FULL POTENTIAL, THIS WOULD REDUCE DIRECT EMISSIONS FROM CEMENT PRODUCTION BY OVER 4 MILLION TONNES OF CO_2 ANNUALLY

The new cements are identified by the CEM II/C-M and CEM VI designations, with sulphate-resistance designated "+SR". These will complement traditional blends such as CEM II/B-V and CEM III/A. Testing has established that all meet the normal minimum strength requirements and their durability has also been successfully characterised and understood.

It has been calculated that the embodied carbon of a clinker-GGBS-limestone blend could be up to 60% lower than that of Portland cement CEM I. In the UK today, 79% of all the cement sold is CEM I. If multi-component cements were deployed to their full potential, this would reduce direct emissions from cement production by over 4 million tonnes of CO_2 annually. ▶

Left: The precast soffits at Farringdon Elizabeth Line Station in London contain 50% GGBS. The Crossrail project also required a minimum of 50% cement replacement for in-situ concrete, but achieved up to 72% where curing times allowed

Below: Hanson's limestone quarry in Ketton, Rutland. Using limestone in multi-component cements will reduce demand for fly ash and GGBS without compromising performance

Photo: Hanson

New cements vs CEM I

The calculations in the table below are based on the established values of embodied carbon for each ingredient of the multi-component mixes. For the methodology, see MPA Cement Factsheet 18 at cement.mineralproducts.org

Table 1: Indicative embodied carbon for different cements and combinations

Cement types			
Cement factory	Combined at concrete plant	Supplementary cementitious material	Embodied carbon ($kgCO_2/t$)
CEM I / Portland cement	n/a	n/a	860
CEM II/A-L Portland limestone cement	CIIA-L		
CEM II/A-M (S-L) Portland composite cement	CIIA-SL	6-20	825-720
CEM II/A-V Portland fly ash cement	CIIA-V		
CEM II/B-V Portland fly ash cement	CIIB-V		
CEM II/B-S Portland slag cement	CIIB-S	21-35	700-585
CEM II/B-M (S-L) Portland composite cement	CIIB-SL		
CEM II/C-M (S-L) Portland composite cement	CIIC-SL	36-50	585-400
CEM III/A Blast-furnace cement	CIIIA	36-65	585-350
CEM III/B Blast-furnace cement	CIIIB	66-80	350-230
CEM IV/B-V Siliceous fly ash cement	CIVB-V	36-55	565-380
CEM VI (S-L) Composite cement	CVI-SL	51-65	400-350

= New cements (shaded rows: CEM II/B-M (S-L), CEM II/C-M (S-L), CEM VI (S-L))

TRANSITION TECHNOLOGIES

Now, new, next: the materials bridging the gap to net-zero

The UK cement sector is working to deploy and scale up carbon capture (see pages 4-9), which has the potential to deliver net-zero Portland cement in the future. In the meantime, replacing a proportion of Portland cement with a supplementary cementitious material (SCM) is a well-established way of lowering concrete's embodied carbon. Here, MPA's concrete experts discuss the SCMs available to specifiers now, the new constituents on the horizon, and what's coming next.

NOW

Ground granulated blast-furnace slag (GGBS)

A by-product of the steelmaking process, GGBS is a proven replacement material and it is well-established in the UK market. Slag is produced in limited quantities at two UK steel works, with the remaining demand met by importing from other markets. There are many reasons why this may be traded globally rather than used in local concrete – for example, there might be no grinding or blending capacity in the country of origin, or GGBS mixes may not be permitted under local standards. The global supply is forecast to continue to increase until 2025, although GGBS will never be able to completely replace the supply of clinker as its production is limited in comparison. It's a valuable tool while it is available but, in the longer term, other SCMs such as calcined clays and natural pozzolanas will come into play.

Noushin Khosravi, sustainable construction manager, UK Concrete

NEW

Recovered fly ash

Coal-fired power production has decreased rapidly in the UK since 2014 and is expected to end by 2024. Most other European countries are aiming to cease production by 2030, at which point demand for fly ash – a by-product of this process – will have to be met by imports from further afield.

However, it is estimated that more than 100 million tonnes of fly ash is stored in stockpiles located at operating and recently closed power stations in the UK, and that 40 million tonnes of this could be used as a cement replacement. Initial findings from testing by the UK Quality Ash Association and the University of Dundee indicate that the processed material can meet the relevant European and US standards. Further testing is under way to provide sufficient data for a performance comparison between power-station-derived fly ash and stockpile-derived fly ash, and to support its inclusion into a future revision of BS 8500.

Gareth Wake, director, MPA Ready-Mixed Concrete

Left: A House for Artists in Barking, Essex. Apparata Architects' housing block used 50% GGBS concrete above ground and 70% below

Above: A recent sample of BioZeroc concrete, which uses bacteria to create a cement-free mix

NEW

Calcined clay

Clay is a naturally abundant material in the UK, and when calcined can be used as an SCM. UK calcined clays are demonstrating performance similar to and better than fly ash, which makes them an attractive material for reducing the embodied carbon of concrete. A current MPA innovation project, supported by Innovate UK, is testing two secondary sources of clay – one arising from overlying rock deposits at mineral extraction sites, the other from brick manufacturing. Using calcined clays from these sources could divert 1.4 million tonnes of material from waste streams every year.

Colum McCague, technical manager, MPA Cement

NEXT

Recycled cement, admixtures, microbes …

We do not yet know which of the next-generation transition technologies will be the ones to take us on the final leg of the journey to net-zero, but there is no shortage of promising contenders. Among potential SCMs, Seratech's technology is based on the abundant mineral olivine and uses CO_2 in its manufacture (see page 9), while recycled concrete paste taps into the unused cementitious properties of crushed concrete. Cambridge Electric Cement is an innovative form of binder manufactured using concrete demolition waste (see page 19).

Beyond cementitious materials, there are numerous innovations that could produce lower-carbon concrete. A graphene-enhanced admixture has been shown to produce concrete with improved early tensile and flexural strength, as well as enhanced durability and fire resistance. This could reduce embodied carbon by requiring less material for reinforcement cover, or for the structure itself.

Advances are also being made in cements that rely on alternative ingredients, such as a chemical activator in place of clinker, to create a binder with similar properties to general-purpose cements but different chemistry. A variety of alkali-activated cementitious materials (AACMs), for example, are available for use, and can be specified using PAS 8820, a publicly available specification produced by standards body BSI. Work is under way to create a BSI Flex Standard to allow specification by performance, in order to facilitate the use of new kinds of binder.

There are many more potentially transformative solutions that will take longer to be deployed at scale: Cambridge-based Biozeroc, for example, is using microbes to "grow" concrete (see left). The concrete of the future could be created using a range of cements and binders, many of them unfamiliar today. ●

Elaine Toogood, director of architecture and sustainable design, The Concrete Centre

Photos: Paul Burroughs; Ståle Eriksen

THE AFTER LIFE

Concrete absorbs carbon dioxide throughout its life cycle – a process that is accelerated by crushing and recycling. Tom De Saulles takes a fresh look at end-of-life assumptions

The University of Warwick Arts Faculty, designed by Feilden Clegg Bradley Studios. The foundations of the BREEAM Excellent building use recycled concrete from the car park that previously occupied the site

Photo: Hufton + Crow

The past, we are told, is a foreign country. And it's true that, when it comes to techniques for construction and demolition, they do indeed "do things differently there". It follows therefore that our future selves will also find new approaches to these tasks, making it tricky to predict what will ultimately happen to the current generation of buildings at the end of their useful lives. Deconstruction and waste handling can produce widely varying carbon emissions depending on the particular waste route – whether it be landfill, waste-derived fuel, or some other form of reuse.

This poses a problem for the whole-life carbon calculations of many materials, but less so for concrete. At the point that a concrete-framed building can no longer be reused, its onward path is relatively simple, centring almost entirely on use as a recycled aggregate (see case study, page 19). Statistics from the Department for Environment, Food and Rural Affairs suggest that around 92% of concrete is reused after demolition and waste processing, mainly in groundworks.

A SUBSTANTIAL PROPORTION OF THE CARBON EMISSIONS ASSOCIATED WITH CONCRETE CAN BE REVERSED

Where the uncertainty lies in the afterlife of concrete is that, during this stage, a substantial proportion of the associated carbon emissions can actually be reversed. This is due to a natural chemical reaction that occurs throughout concrete's lifespan but can become more active during and beyond end-of-life. Known as carbonation, this process is often overlooked, but is key to accurately gauging concrete's overall carbon impact.

Reversing slowly – then quickly

The science behind carbonation is fairly straightforward and can be summarised as follows: the manufacture of one tonne of Portland cement produces around 0.67 tonnes of direct CO_2 emissions to the atmosphere. In the UK, 33% of this is from the fuel used, and around 67% is from a chemical process called calcination, which results in the formation of calcium oxide (CaO). This then reacts with CO_2 in the environment and absorbs it into ▶

Visualisation: Carmody Groarke

the concrete – or, in other words, carbonates it.

According to the method for calculating carbonation set out in the standard BS EN 16757: 2022, this process can result in up to 75% of the CO_2 emitted from calcination being reabsorbed during concrete's primary and secondary lives.

In reinforced concrete, very little carbonation occurs until the demolition and waste processing stage. Because carbonation can corrode steel, the mix design deliberately slows its progress, limiting the reaction to the surface layer during the life of the building.

ACCORDING TO THE BRITISH STANDARD, THIS PROCESS CAN RESULT IN UP TO 75% OF THE CO_2 EMITTED FROM CALCINATION BEING REABSORBED

In lower-strength concrete such as blockwork, the absence of reinforcement means that corrosion is not an issue. The process is therefore quicker, often resulting in complete carbonation during the in-use phase (without negatively affecting strength).

A working method

In terms of whole-life performance, CO_2 uptake from carbonation is included in the concrete sector's

Above: The facade of Carmody Groarke's extension to the Design Museum Gent in Belgium will be composed of pale bricks made from recycled crushed concrete and other locally sourced municipal waste streams

Opposite: The Gent Waste Brick is cured rather than fired, gaining strength from carbonation

Photo: Cinzia Romanin and Thomas Noceto

environmental product declarations (EPDs) for generic ready-mixed and precast concrete products, covering all stages of the life cycle. Product-specific EPDs from manufacturers may not account for carbonation, so this should be checked when undertaking a carbon assessment, as should the general inclusion of carbonation in the life cycle assessment tool being used.

The "standard method" for calculating carbonation detailed in BS EN 16757: 2022 can be used when producing EPDs (see below). It gives CO_2 uptake results expressed as $kgCO_2$ per m^2 of concrete surface, which can also be applied to concrete building elements to give the life cycle CO_2 uptake from walls, floors and so on. Use of the calculation is relatively straightforward for the in-use ▶

CALCULATING CARBONATION

A model for counting concrete's hidden carbon absorption

Carbonation of concrete is scientifically well-established and recognised by the Intergovernmental Panel on Climate Change as an important, permanent, carbon emissions sink. Funded by the Department for Energy and Net Zero (previously BEIS), MPA has developed a UK-specific model of CO_2 removals from the atmosphere, which it is using to improve the representation of carbonation in EPDs.

The rate at which concrete carbonates depends on its strength and its exposure – whether it is outdoors, indoors, covered or buried. In order to calculate the CO_2 uptake during its primary service life, five typical concrete applications have been considered:

- Steel composite frame buildings, such as offices and other commercial developments
- Concrete-frame buildings such as high-rise residential towers
- Masonry buildings, such as houses and low-rise apartment blocks
- Infrastructure projects
- Mortar and merchant sales of bagged cement.

Together, these applications account for 80-90% of the UK market. For each application, a typical building/infrastructure prototype has been identified and the CO_2 uptake over its primary service life calculated, using the standard method in BS EN 16757: 2022.

In applications that use high-strength reinforced concrete to limit the depth of carbonation – that is, infrastructure and buildings with steel composite or concrete frames – the estimated CO_2 uptake in primary use is understandably low. In contrast, carbonation will have penetrated throughout the entire low-strength concrete blocks used in masonry construction by the end of their primary life. Cement mortars also quickly carbonate through their full depth and have the highest CO_2 uptake.

For high-strength concretes, where there is little penetration of carbonation during primary use, the BS EN 16757 standard method for calculating CO_2 uptake can also be applied in the end-of-life stage (module C in EPDs) and in secondary use. Following demolition, concrete is typically crushed and stored on site, before being reused in groundwork applications, such as piling mats and road bases (see overleaf). Crushing concrete considerably increases its surface area, so leads to a corresponding increase in CO_2 uptake. The level of absorption depends on how coarsely or finely the concrete is crushed, and the length of time and conditions under which it is stored.

Carbonation will continue when the crushed concrete enters secondary use in groundworks, albeit more slowly than when it is exposed above ground. BS EN 16757 advises that, ultimately, up to 75% of the process or calcination emissions from cement manufacture can be reabsorbed.

Rachel Capon, UK Concrete

Photo: Noshe

phase and the standard includes worked examples.

For module C of EPDs (covering end-of-life), the methodology is less prescriptive and essentially suggests that the approach must be determined by the end-of-life data available at a project-specific level or by applying a national provision, which can be in the form of a default value. Use of a national provision is also suggested as an option for estimating secondary-life carbonation, which is treated in the standard as an important element of the total carbon footprint.

The Mineral Products Association (MPA) is developing a national provision for end-of-life carbonation based on current standard practice for UK demolition and waste processing.

CARBONATION STILL CONTINUES BELOW GROUND, ALBEIT AT A SLOWER PACE

This provision would cover concrete's secondary life as a recycled aggregate used in a variety of applications including groundworks, piling mats and landscaping. Although much of the concrete used in these applications is not directly exposed to the air, carbonation still continues, albeit at a slower pace, below ground. The secondary life may be 100 years or more, so this stage can be responsible for a significant proportion of overall carbonation.

A complete picture

Carbonation is a good example of why whole-life carbon assessments are important if you want to properly evaluate the environmental performance of buildings and the materials they are constructed from. As carbonation can reabsorb up to 75% of the CO_2 emitted from the calcination process, and as calcination accounts for most of cement's initial embodied carbon, it clearly has the potential to gradually but significantly reduce the whole-life carbon footprint of concrete.

While this type of assessment cannot avoid the need for end-of-life assumptions, we can nevertheless be confident that, for any concrete used, a useful amount of carbonation will occur during waste processing and beyond. This is an important consideration for UK building assessors and carbon modellers as ultimately, in the absence of specific regulations, it is up to them to decide how materials should be accounted for at end-of-life. ●

Tom De Saulles is building physics advisor at The Concrete Centre

Above: David Chipperfield Architects' Kunsthaus Zurich was built from 98% recycled concrete.In Zurich, to qualify as recycled concrete for use on public buildings, it must contain either 50% recycled concrete aggregate or 25% mixed demolition waste aggregate

CASE STUDY: DAY AGGREGATES

The next frontiers in concrete recycling

Government statistics suggest that 92% of concrete is salvaged for recycling when it comes to the end of its primary life. So what happens to it?

Day Aggregates has been recycling concrete for several decades, and now produces between 750,000 and 1 million tonnes of recycled aggregate every year. In the late 1990s, it moved from using mobile crushing equipment on building sites to establishing permanent processing facilities at its plants in Brentford, Greenwich, Crawley and Purley, both to increase output and improve product control. "We saw the resources that were coming out as construction demolition waste," explains director Adam Day. "We thought, if we put in the infrastructure to manufacture it correctly, we could get to a point where that resource is actually reused effectively and efficiently. And that's where we've got to today."

The four recycling plants are in or just outside London, where concrete, often from high-rise buildings, accounts for the majority of demolition waste. Day Aggregates reprocesses this for use as unbound material, usually as a base for roads and pavements or back-fill for bridges. These applications make up 50% of the UK aggregates market and would otherwise rely on virgin materials, which would have to be transported into urban areas from quarries.

To process the concrete, a jaw crusher first reduces the size of the rubble before it is screened and graded. It is then hand-sorted on conveyor belts to remove foreign elements such as plastic and wood, while air separation filters out less dense materials, including light brick and blockwork. Finally, a horizontal shaft impactor shapes the concrete fragments. "For roads, we want them to be interlocking so we take out any elongation," explains Day, adding that bases and fill use an "all in" size of 0-32mm.

The next frontier is to recycle concrete not as aggregate, but as new concrete. The challenge – but also the greatest potential in terms of carbon reduction – lies in removing the cement from crushed concrete, explains Day. "Unfortunately, new cement paste doesn't like adhering to old cement paste. You also need to be able to control the water content in concrete, and old cement draws in water, which makes it very difficult to reuse in higher-grade structural applications."

Day Aggregates is working on a two-year trial with the Cement 2 Zero project, which involves a method of mechanically stripping away the old cement, thereby exposing the surfaces of the original aggregate. Crucially, the cement too will be reactivated: an electric arc furnace will transform it into a clinker, which can then be ground into new cement powder, known as Cambridge Electric Cement. "Cement substitutes such as fly ash and GGBS are well proven and very much embedded in design," says Day, "but we will need to move on from just relying on these sources, which are finite. This is a new method of closing the loop."

Photo: Day Aggregates

TURNING OF THE TIDE

The mammoth Thames Tideway Tunnel is a 25km addition to London's Victorian sewage network, to make it fit for the future. Low-carbon concrete has been used for more than 87,000m^3 of permanent structures on the eastern tunnel sections, with mixes optimised to include up to 73% GGBS. By the end of August 2021, this was calculated to have already saved 125 tonnes CO_2e.

Photo: Tideway