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 …

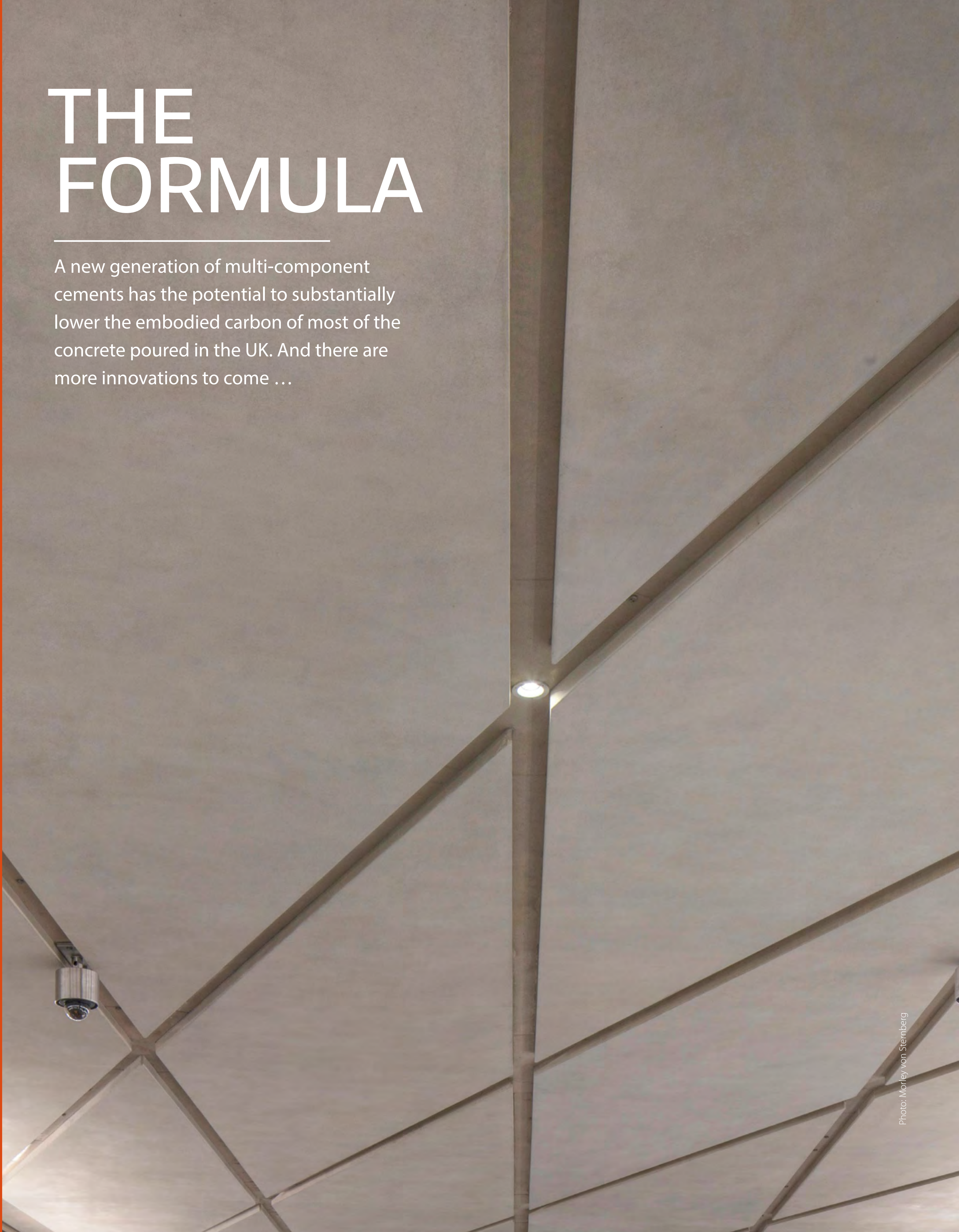

Photo: Morley von Sternberg

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.

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. ▶

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

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