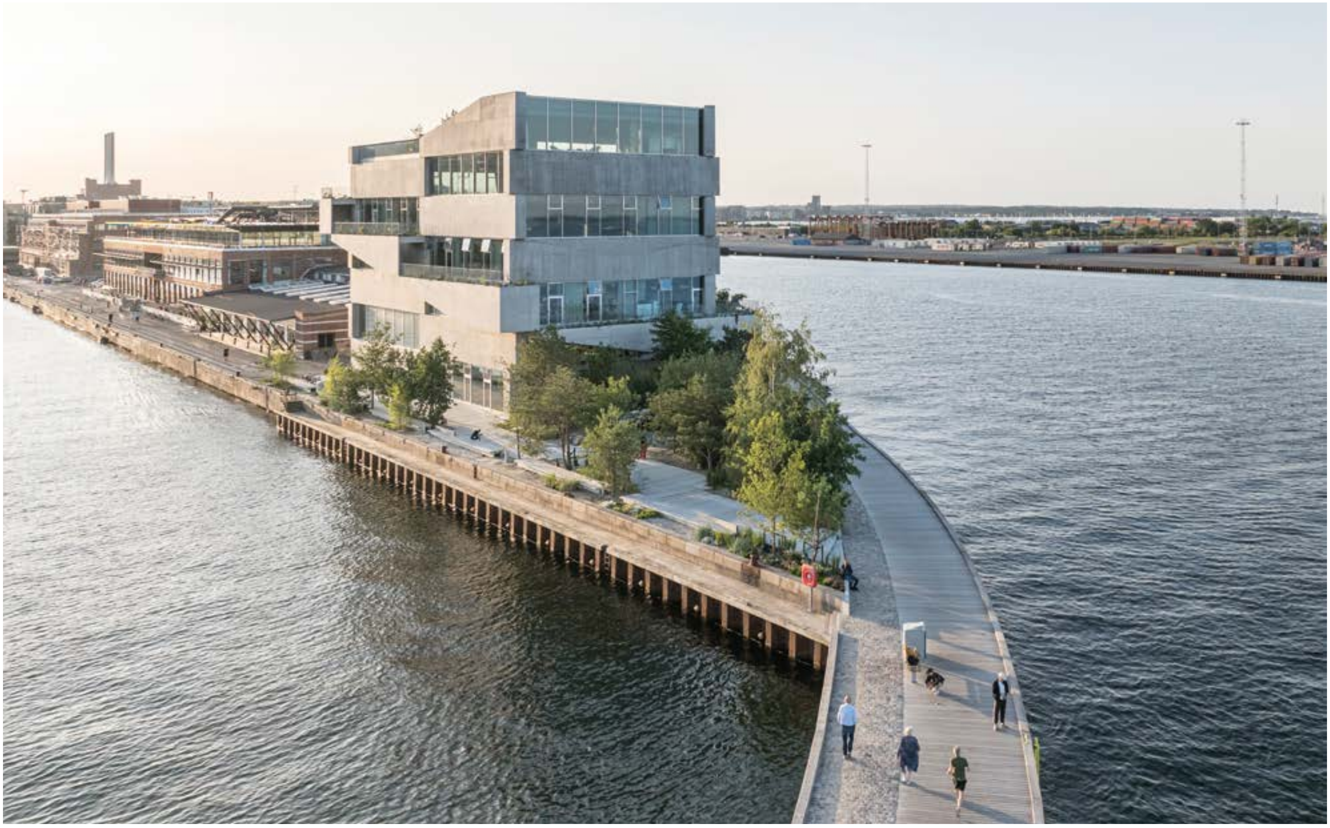

Photo: Laurian Ghinitoiu

ALL IN THE BIND

The race is on to find alternative SCMs. Tony Whitehead reports on the latest research into three of the most exciting potential sources: waste clay, recovered fly ash and recycled concrete fines

You probably know concrete comprises a combination of sand, stone and cement. But ever since it was invented, concrete makers have been interested in using alternative binding materials to alter its properties. Now, of course, there is an urgent new reason for exploring other cementitious materials: the process of making Portland cement is carbon-intensive, so swapping it out for supplementary cementitious materials (SCMs) can dramatically reduce the embodied carbon of concrete.

"The most used SCM in the UK is GGBS (ground granulated blast furnace slag)," says Diana Casey, executive director, energy and climate change, at the Mineral Products Association. "Replacing around 50% of the Portland cement with GGBS will currently reduce embodied carbon by about one third. Fly ash has also been widely used in the past"

But fly ash and GGBS derive from coal-fired power stations and coke-fuelled iron blast furnaces respectively, technologies now being removed from the UK's industrial landscape. "These products can be imported to meet demand, but there is an opportunity to explore alternative options that could be sourced domestically," says Casey. "So the race is on to find new low-carbon SCMs that can be widely specified. It is a fascinating area of research."

Fascinating, and perhaps more complex than is generally appreciated. A recent webinar on SCMs held by The Concrete Centre focused on three current areas of exploration (see below), and listed ten main criteria for innovative SCMs: CO_2 mitigation potential, implications for energy and water demand, cost, consistency, how easily it can be scaled up to commercial production, how widely available it is, whether it is a local or imported resource, how it affects the properties of concrete, potential applications, and how readily it can meet existing standards. There is also the extent to which using an SCM can help to cut waste from other industries, by repurposing it as a resource.

Before any material can be added to concrete it must undergo exhaustive, extensive research and testing. So, how does an interesting idea become a commercial reality?

"It often starts quite informally," says Moray Newlands, reader at the University of Dundee. "You might have a conversation at a conference which leads to further discussions. People who are interested in this, in academia and in industry, tend to know each other anyway, so there is a fairly constant exchange of ideas."

Calcined clay

Newlands has recently spent two years researching calcined clay – clay that has been heated to around 850°C to make it more chemically reactive. "This is not a new idea, it's been used in concrete for centuries," he says. "But if it is to become more widely used, then more needs to be understood about how it works. For example, we need to define exactly which clays we are talking about, how they are processed, and how they are added to the mix. We then need to analyse how the clay SCM has affected the concrete – its usability, strength, durability and so on."

Newlands' study, funded by Innovate UK and undertaken with University College London (UCL) and industry partners including Heidelberg Materials,

"USING RECLAIMED CALCINED CLAY COULD REDUCE THE EMBODIED CO_2 OF CEMENT BY AROUND 10-30%"

Imerys, Forterra, Tarmac and the MPA, focused on the potential for using waste clay, specifically the interburden or overburden from quarries. They also tested waste from brick manufacture – effectively clay that has already been calcined. "Our colleagues at UCL did a lot of work investigating the chemistry of these clays, looking at optimum calcination temperatures and how they might perform in cementitious systems, and in particular how they might affect concrete rheology, or flow."

Of the ten clays initially studied, four were chosen for further research. "The kaolin content of clay is generally held to be important for how well it performs in concrete, so we chose clays with different kaolin contents, ranging from 20-90%, to test this in practice."

To create the SCM, the clays were heated in large, pilot-scale furnaces, then processed to achieve a fineness that could optimise reactivity and provide consistent powder for comparison. "We found that even when different clays have particles of similar size, the shape and surface area of the particles could vary quite a bit. That impacts how they perform – affecting water and admixture demand, for example."

Researchers at Dundee then created no fewer than 37 different concretes that would conform to BS 8500 (the key UK standard for specifying concrete) – including concrete with composite cements where limestone fines (very finely ground calcium carbonate) was added along with the calcined clay.

As a measure of just how thorough such research must be, they were careful to test different sources of both cement and limestone fines to ensure that any small variation in these base materials did not unduly skew the analysis. It also tested a range of different water/cement ratios and analysed the amounts of superplasticiser required to meet slump test requirements. "These actually varied quite a bit with different clays, but all were within the normal ranges as specified by the suppliers," says Newlands

Perhaps the most surprising result was the effect of calcined clay on the strength of the concrete: "The clays were clearly highly reactive, particularly early in the curing process. Strength gain between 3 and 14 days was remarkable. Interestingly, the clay with the lowest kaolin content performed much better than expected."

His team also tested how the concretes performed in terms of rate of carbonation (slightly higher than normal) and chloride migration (lower than normal). "But well within acceptable parameters in both cases."

Finally, they were handed over to precast manufacturer Forterra, which used the calcined clay in self-compacting concretes to make a number of retaining wall units as test structures. "Forterra reported that the concretes flowed well," says Newlands. "We will go back periodically and see how the units are doing: check ongoing ▶

Opposite: At the Bjarke Ingels Group headquarters in Copenhagen, 30% of the Portland cement clinker in the external structure was replaced with calcined clay. BIG says this has reduced the embodied carbon of the concrete by 25%

Below: Researchers at Dundee University created 37 calcined clay concretes that would conform to BS 8500. They studied ten different waste clays, with kaolin content ranging from 20-90%

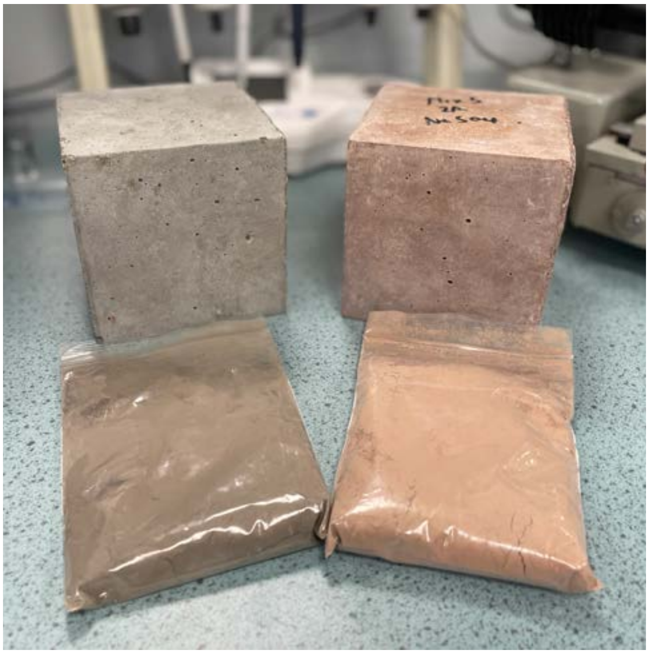

Photo: University of Dundee

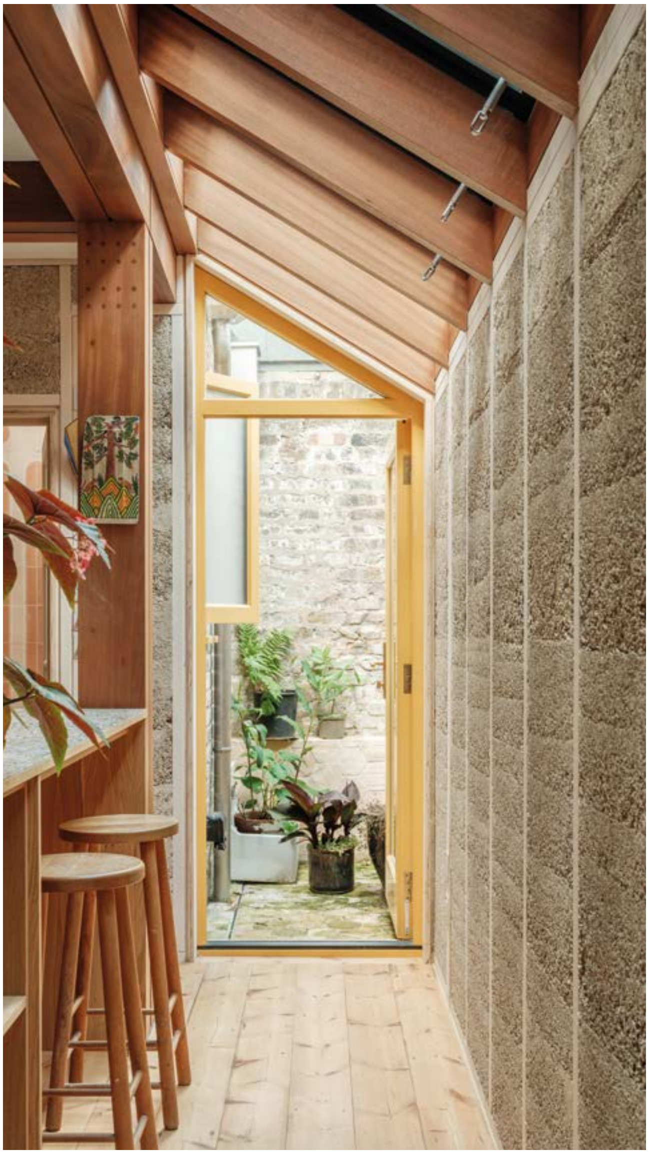

Photo: James Retief

QUICK FACTS: THREE NEW SCMs

Waste-derived calcined clay

Source: Waste clay from quarries, manufacturing by-products and excavation during construction
Key process: Heated to approximately 850°C for three hours
Potential maximum replacement level: 55% (typical replacement will be around 30%)
Pros: Early strength gain, high chloride resistance
Cons: Slightly higher carbonation in low-strength mixes
Can it be specified under BS 8500? Yes
Estimated embodied carbon: 0-250kgCO_2/t

Recovered fly ash

Source: Stocks from decommissioned coal-fired power stations
Key process: Drying, deagglomeration, electrostatic carbon removal
Potential maximum replacement level: 55% (typical replacement will be around 30%)
Pros: Extraction rate can be geared to demand
Cons: Careful processing required to maintain full reactivity
Can it be specified under BS 8500? Not yet
Estimated embodied carbon: 94kgCO_2/t (with significant potential for further reductions)

Recycled concrete fines (RCF)

Source: Concrete waste from construction and demolition
Key process: Crushing, plus exposure to CO_2 or calcination at 550°C
Potential maximum replacement level: 35% (typical replacement will be around 15%)
Pros: Upcycles concrete demolition waste
Cons: Fine contaminants can compromise performance
Can it be specified under BS 8500? Not yet
Estimated embodied carbon: Awaiting project results

carbonation, for example, and see if there are any micro-structural developments we need to be aware of."

Newlands believes that the work he and the team have done on reclaimed calcined clay has the potential to make a real difference – both on site and in terms of the contribution SCMs can make to getting the concrete industry to net zero and beyond. "Our research shows these materials are ready for industry use and can be specified and supplied to BS 8500 when they become commercially available. Using these cements in the UK could cut waste by 1.4 million tonnes, and reduce the embodied CO_2 of cement by around 10-30% compared to normal CEM I cement." This research complements the work being carried out by the University of Leeds with the British Geological Survey (Concrete Quarterly 287, Summer 2024), as well as the practical application of calcined clays on HS2.

Recovered fly ash

Clay is just one of several waste materials to have been successfully studied as an SCM. Stockpiled fly ash from coal-fired power stations is also being assessed with a view to using it more widely in the UK construction sector.

When the UK's last coal-fired power station closed in 2024, domestic production of coal-derived fly ash (CDFA) fell to zero, points out Nigel Cooke, director of the UK Quality Ash Association (UKQAA). "However, power stations that have closed over the past 15 years or so have left behind large stockpiles of CDFA. We've been researching whether this resource could be used as an SCM, looking at it from both a scientific and a commercial point of view."

One of UKQAA's first tasks was to

map the stockpiled ash. "We found significant stocks at 16 former power station locations," says Cooke. "They ranged from 5-50 million tonnes each, and totalled well over 100 million tonnes altogether. But the ash has been in the ground for many years, so the next step was to check whether it was still reactive and suitable for use in concrete."

With the help of material processing specialist Atritor, large samples of ash were dried, deagglomerated and sieved to achieve a consistent fine ash comparable with fresh CDFA. Finally, the ash was fed through a 4,000V electrostatic separator, to remove any carbon that remained (or the vast majority of it).

According to Cooke, the results have been encouraging: "The chemistry of the stockpiled ash is, as you might expect, very similar to fresh. There is a slight decrease in reactivity, but this can be compensated for by ensuring that there is a significant particle size range below 10 microns."

This increases reactivity by increasing surface area, he explains, though it must be balanced with the additional processing cost and the potential to lose the ash's distinctive spherical particle shape. "That's the unique feature that helps it reduce the water requirement and improve the flow of the concrete."

Unfortunately, drying and processing does come with a carbon cost: "We did a desktop study looking at all the processes from extraction to final product, and we calculate the carbon cost to be 94kgCO_2 per tonne of processed stockpiled ash," says Cooke. "If you can use green energy and waste heat, there's considerable potential to lower that figure. But even at a cost of 100kg/tonne, CDFA still delivers a carbon saving of up to 760kg for every tonne of cement it replaces."

He is convinced that CDFA can make a significant contribution to UK construction for many years to come: "The stockpiles contain decades of supply. Rumours of the demise of fly ash in the UK have been greatly exaggerated."

Treated recycled concrete fines

Another waste material currently attracting interest as an SCM is concrete itself, or rather recycled concrete fines (RCF). When concrete from demolition is crushed for use as recycled aggregate, about 15% is too fine to be used. This material is the subject of research led by the Materials Processing Institute (MPI), in partnership with the MPA, Aston University and Mott Macdonald. "RCF behaves in a similar way to limestone when it's left untreated," explains Roger Griffiths, manager, innovation projects, at the MPA. "According to European standards, it can replace up to 35% of cement in concrete, although 15% is a more realistic level. But it can also be treated, either by exposing it to a CO_2-rich atmosphere, or by calcinating it at around 550°C. Then it becomes more reactive and can potentially replace a higher proportion of the cement."

> "RUMOURS OF THE DEMISE OF FLY ASH IN THE UK HAVE BEEN GREATLY EXAGGERATED"

The project, which will complete in July 2025, is studying both treated and untreated RCF, analysing its effects on concrete's strength and durability, and its carbon reduction potential. "It will also prepare recommendations on how to use RCF in cement and concrete, so they can be added to the relevant British Standards, especially BS 8500," says Griffiths. "This is crucial if industry is going to have the confidence to specify RCF."

Whether they contain clay, ash, recycled concrete fines, or another alternative binder, low and lower carbon cements are set to play a vital role the decarbonisation of concrete. Multi-component cements have been successfully incorporated into BS 8500, expanding the use of powdered limestone in lower carbon concrete. UK Concrete estimates that SCMs will account for 12% of the carbon reduction still required for the industry to reach net zero by 2050.

But such is the interest in SCMs, that percentage could turn out to be a conservative estimate. In 2023, supplementary cementitious materials made up approximately 30% of the total cementitious materials used. "With the development of these innovative materials, the landscape for SCMs is changing and our knowledge of clay, ash, RCF and other SCMs is increasing all the time," says Casey. "They have great potential, and that's very exciting, both for the scientists working to understand them, and for us as an industry. We are on our way to net zero, and SCMs are clearly going to be a big part of that journey." ●


Photo: HS2

Right: Waste clay excavated from the London tunnels for HS2 is being calcined and reused in concrete foundations, walkways and platforms. The project team includes Skanska, Arup, Tarmac, the University of Leeds, Sika UK, Expedition Engineering and the MPA

Opposite: The floor slab of House Made by Many Hands in east London, designed by Cairn Architects, was built using limestone calcined-clay cement (LC3), a multicomponent cement made with 30% calcined clay and 15% limestone