Fact Sheet 12

Novel Cements: Low energy, low carbon cements

Background and introduction

Sustainability and the UK cement industry

Traditional Portland cement-based concrete forms the 'bedrock' of the built environment. Buildings that incorporate it appropriately and imaginatively can and do exhibit an impressive array of properties[1] especially those that have been designed to optimise the thermal mass of concrete[2]. This type of concrete building is expected to adapt best to the UK's changing climate[3, 4].

The demands of 'sustainable development', however, place a responsibility on the construction sector to continuously improve existing processes, products and practices, and to innovate in order to reduce: energy used in service; embodied energy in products and emission of green house gases both during manufacture and from buildings. BCA and its Member Companies have their part to play in responding to this sustainability agenda and have a vision/strategy[5] for delivering a sustainable cement industry into the future, incorporating a 'carbon strategy' for reducing carbon dioxide (CO_2) emitted from the manufacturing process[6]. As but one part of the industry's contribution, is the recognition that it must evaluate the viability of alternatives to Portland cement CEM I, the fundamental ingredient needed to produce traditional concretes.

Cements

Novel cements (i.e. those based on a non-traditional process or raw materials) that embody less energy and emit less CO_2 during manufacture than does Portland cement CEM I are known; some are already in production whilst others are at varying stages of development. This Fact Sheet examines three of the more interesting of these novel cements and reviews their prospects for manufacture and acceptance in the UK. For a fuller discussion of the scientific and social issues involved in developing novel cements, see Gartner[7].

Making Portland cement CEM I

The manufacture of Portland cement CEM I involves quarrying limestone or chalk, grinding it very finely and mixing it with clay or shale, before heating it in a rotating kiln to 1450ºC. At that temperature, a chemical change takes place, where the raw materials turn into a volcanic rock-like material called clinker. When cooled, the clinker is ground with about five percent gypsum, added to control the setting time of the end product. The overall process, is though, relatively energy-intensive, and CO_2 is emitted during the chemical changes that take place during heating

One way to reduce both of these environmental impacts is to maximise the use of secondary cementitious materials such as granulated blastfurnace slag, coal fly ash and natural pozzolans during manufacture; cements of types CEM II, III, IV and V are produced via this route. An alternative option is to explore more 'novel' products and processes that are inherently less energy and CO_2-intensive i.e. the low energy, low carbon route.

What are low energy, low carbon cements?

Although there is no precise definition, low energy, low carbon cements would generally be understood to have some or all of the following characteristics: they would:

- be manufactured using a novel process that, ideally, utilises waste-derived fuels and raw materials;
- embody less energy than 'traditional' Portland cements, including those that contain additional inorganic/mineral constituents;
- be expected to reduce both waste and emissions.

Three specific types, either already in production or under investigation and that can fulfil the above characteristics are considered here, they are:

- 'eco-cement' based on magnesium oxide (Tasmania);
- low energy CSA-belite cements (China);
- 'eco-cement' based on municipal solid waste incinerator ash (Japan).

What are magnesium oxide-based cements[8]?

Magnesium oxide-based eco-cements have been invented and patented by TecEco in Tasmania. To date, small commercial quantities have been made to produce non structural products such as concrete bricks, blocks and pavers.

There are two distinct forms of these eco-cements. A type in which the main reactive constituent is magnesium oxide, mixed with industrial by-products such as coal fly ash or blastfurnace slag and a type where magnesium oxide is mixed with Portland cement clinker and a pozzolan, to form a 'composite cement'.

The magnesium oxide precursor is produced by heating magnesium carbonate, preferably as the mineral magnesite, to its dissociation temperature of about 650 °C. At the same time a quantity of CO_2 is given off as a further reaction product.

In comparison, Portland cement CEM I is based on calcium oxide and this is produced by first heating calcium carbonate (limestone) to dissociation at around 900 °C, again with liberation of CO_2. At this stage in the process, the quantity of CO_2 released is less than that from an equivalent mass of magnesium carbonate but the calcium oxide, plus other ingredients, is then heated to 1450 °C to produce clinker. This temperature increase is accompanied by liberation of yet more CO_2 during combustion of the fuel, with the resulting total being greater than that emitted during dissociation of the same mass of magnesite.

When magnesium oxide-based eco-cements are mixed with water and aggregates/by-products to form concrete, the magnesium oxide hydrates to magnesium hydroxide (brucite), which is said to be the main binding phase. Strength, especially at exposed surfaces, is said to be further enhanced by rapid atmospheric carbonation of relatively porous small scale products, a process claimed to sequestrate enough CO_2 to compensate for most of that liberated during manufacture of the cement.

Can magnesium oxide-based cements be manufactured in the UK?

In principle, magnesium oxide-based cements could be manufactured in the UK but in practice this would seem to be very unlikely. Manufacture would be critically dependent on the availability of the basic raw material and its proximity to a production facility. The preferred raw material is the mineral magnesite and whilst this is abundant in mainland Australia and Tasmania, there are no significant deposits in UK.

The main source of magnesium carbonate in UK is high-magnesium dolomitic limestone; dolomite is a mixed calcium-magnesium carbonate. Very few UK cement works are located close to deposits of dolomitic limestone. This is deliberate, as Portland cement manufacture requires a low-magnesium limestone as feedstock in order to limit the formation of periclase (a form of magnesium oxide) that can lead to unsoundness in cement. Therefore, as a minimum, there would be a significant increase in traffic movements required to transport the raw material to existing kilns, with consequent environmental impacts. Similarly, the environmental impacts, capital costs and market uncertainty of building new plant close to deposits of dolomitic limestone for manufacturing a non-Portland eco-cement, unfamiliar to the UK construction sector, would also be significant.

What are CSA-belite cements[9]?

Manufactured and used successfully on an industrial scale in China for about 20 years, (calcium sulfo-aluminate) CSA - belite cements are made by heating/sintering industrial wastes such as coal fly ash, gypsum and limestone at 1200 – 1250°C in rotary kilns.

CSA-belite (β-C_2S i.e. dicalcium silicate) cements are made in a range of compositions but the structural grades made in China comprise a predominant phase of CSA of 35 – 70 %, a belite content below 30% and a 'ferrite' (calcium ferroaluminate) phase of 10 – 30 %.

In comparison with Portland cement CEM I, energy savings can be as high as 25 %, with limestone reductions of 60 % together with reductions in CO_2 emissions of around 20 %.

Where composition has been optimised for early strength, this can be as high as 35 MPa at 24 hours – similar to the 2 day strength of Portland cement CEM I – and 60 MPa at 28 days – about the same as for Portland cement CEM I at the same age.

Can CSA-belite cements be manufactured in the UK?

In principle, CSA-belite cements could be manufactured in the UK. There are no intrinsic technical, process or material supply barriers to their production. However, much applied research and many plant-level pilot studies would be needed to verify that local materials and existing plant could produce consistent high quality product. In addition, well in advance of any production, manufacturers would need to be certain that:

- the regulatory framework governing their licence to operate (known as 'permitting') would not penalise the new process/product unjustifiably;
- economic conditions would be conducive to producing a new and unfamiliar cement in competition with, or in place of, traditional cements;
- and that market acceptance/use would follow from the range of confidence-building measures that would be needed to 'benchmark' performance and to reassure construction sector stakeholders.

What are eco-cements based on municipal solid waste incinerator ash (MSWIA)[10]?

These eco-cements, manufactured in Japan, are in fact traditional Portland cements in their mineralogical composition but processed from raw materials where 50% has been replaced by municipal solid waste incinerator ash (MSWIA), and/or sewage sludge, and where waste oils, non-recyclable plastics and refuse-derived fuels have replaced fossil-fuels.

MSWIA eco-cements are also lower energy cements in that 'clinkering' takes place in a rotary kiln at 1350°C rather than at 1450°C, as is the case for traditional Portland cement clinker.

With the exception of a specialised rapid-hardening, high chloride type produced for particular applications, but unsuitable for use in structural concretes, these eco-cements are virtually indistinguishable from Portland cement CEM I and consequently have the same properties, performance and applications.

What about chlorides and dioxins in MSWIA?

MSWIA generally contains high concentrations of chlorides as well as small amounts of toxic substances such as dioxins and heavy metals. In consequence, both the process and the product are engineered to be safe with respect to human health and impacts on the environment. To this end, any dioxins initially present are completely decomposed above 800°C, so that the product is free from them and kiln exhaust gases are quickly cooled below 250°C to prevent re-formation of dioxins in the cement kiln dust (CKD). Some volatile heavy metals, such as lead, zinc, copper and cadmium vaporize during clinkering in the form of chloride salts and are trapped in the CKD. The metals are then extracted from the CKD via a metal recovery process and delivered to smelters for refining.

Can cements based on MSWIA be manufactured in the UK?

There would seem to be no obvious technical barriers to production in the UK. However, manufacture would be critically dependent on the availability of MSWIA and its proximity to existing cement works. Currently, this is in short and irregular supply in the UK but even if this were not to be the case, 'public perception' issues could arise that could far outweigh all others. Hence, the likelihood of producing a familiar Portland cement by this process is, in present social, economic and regulatory conditions, low to very low.

What position does BCA take on low energy, low carbon cements?

The BCA welcomes, and aims to be involved with, any initiatives that could lead to a reduction both in the cement industry's contribution to environmental impacts such as emissions of CO_2 – currently at around 2% of the total in UK[11] – and to the amount of energy embodied in cement and, hence, in concrete, buildings and structures.

BCA's current involvement in new areas extends from monitoring international developments to active participation in steering a particular government part-funded research programme on environmentally friendly cements[12].

BCA's Member Companies have long recognised the 'business case' for reducing environmental impacts associated with their current cements and by reducing primary energy use and dust emissions, year-on-year, operating costs have also reduced. Although not as 'newsworthy' as the adoption of a new process, these incremental efforts will continue into the future until, inevitably, an irreducible minimum is reached.

The demands of the free market and environmental regulations will ensure that the industry seeks alternatives to current processes and products but only time will tell whether any will be viable.

Are there barriers to take up of low energy, low carbon cements?

The UK construction sector is often perceived to be 'conservative' in its attitude to new ideas, products and processes. However, such an attitude arises from moral and legal obligations on design engineers and regulatory authorities to minimise the risk of 'structural failure' in order to safeguard society. Innovators, however, will experience this conservatism, and its associated demands, as a considerable barrier and may believe it has been raised simply to frustrate their objectives.

Establishing 'fitness for purpose' for a new cement, low energy, low carbon or otherwise, is neither a simple nor a linear undertaking and the more unfamiliar the cement type the more exacting will be the validation process. Justifiably, stakeholders expect buildings and the infrastructure to be safe, long-lasting and without need of excessive maintenance.

Undoubtedly, a non-Portland cement will face the most arduous route to acceptance. Unfamiliarity with process and product will demand a rigorous, independent technical validation of the cement, leading, at an initial stage, to some kind of formal certification. National or European standardisation would, if sought, follow much, much later when the product had established itself as 'tried and tested'. Even when appropriately validated, use of the cement in structural concrete may well meet with resistance, particularly from specifiers as the representatives of the user-community. Specifiers will be aware that existing Codes of Practice and national construction regulations do not recognise the unfamiliar cement and cannot, therefore, provide a 'deemed to satisfy' solution. Confidence building measures would be needed and early use in non-structural, less demanding applications, would be obligatory until a 'track record' had been established. Use in structural applications could well require the proponents to underwrite performance by way of insurance bonds or other indemnities within demonstration projects. General use would require acceptance as a permitted material in the concrete standards and in engineering Codes of Practice.

Conversely, a novel process that produced a Portland cement CEM I, but a low energy, low carbon type, would have the benefit of familiarity, existing documentation at every level and the 'historical record' of reliability. Market confidence would already be high and validation would be more a matter of reassurance.

Where can I find out more?

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