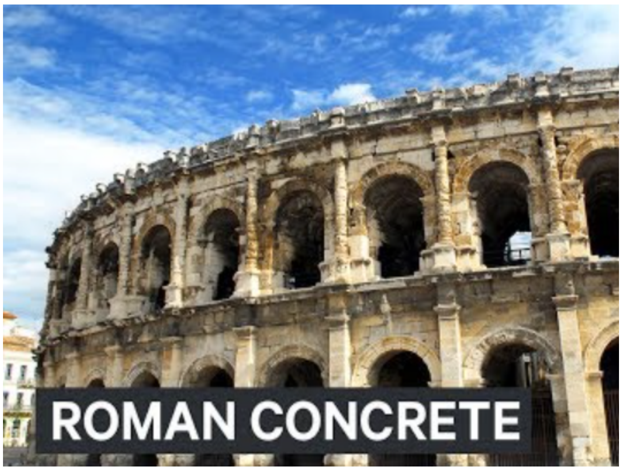
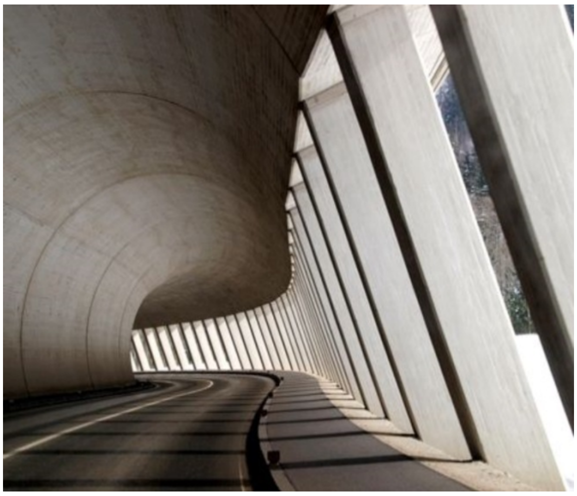
A brief history of concrete and the role of SCMs in reducing environmental impact

Concrete is a vital human invention that has come to define many civilisations. From ancient times it was utilised to build structures of mass and permanence. Structures such as the aquaducts, sewers and bridges constructed by the Romans are a testament to the versatility and longevity of concrete. After many hundreds of years in service, they continue to function and provide confidence to future builders that concrete is a practical and dependable material for construction.



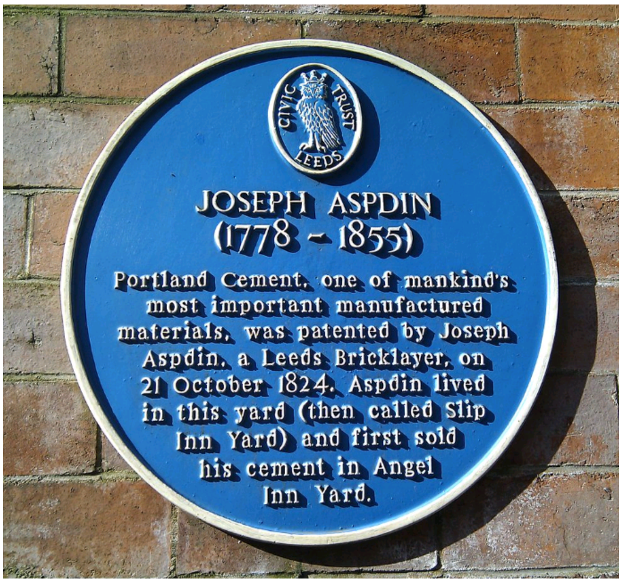


Our modern structures are stronger and more durable due to continued innovation in the design and manufacture of concrete. As for the future, scientists are already working on a form of concrete that will be used to establish a civilisation on a nearby planet such as Mars. The first colonist will bring most of what they need with them including temporary structures, but a permanent colony will require permanent structures. The basis of their research is to manufacture the concrete from ingredients found in abundance on the red planet itself.

So, what is concrete?

Unlike steel, aluminium or plastic, the word “concrete” does not refer to a single material. It is a composite made up of many materials. In simple terms it is made by combining aggregate (most commonly~~,~~ stone and sand) with a binder (most commonly cement and water). The aggregate is normally inert and acts as a passive spacer, relying on the binder to lock it into a solid matrix. The binder is the active ingredient that imparts the largest influence over the properties of the hardened material. For this reason, the binder receives a great deal more attention and becomes the focus of what is to follow.

So~~,~~ what is cement?



Modern cement (most commonly Portland Cement) is based on Joseph Aspdin's patent of 1824, on development of a material that (once hardened) resembled the naturally occurring stone quarried on the Isle of Portland, off the British Coast.

Many improvement have occurred since 1824, with changes in Portland cement's chemistry and production that led to better consistency, quality and economies of scale – particularly~~,~~ after the introduction of the continuous rotary kiln in the late 1850's.

Today cement is defined as a "hydraulic" material (as it reacts with water). It is made by combining predominantly limestone (ancient organic sedimentary rock that forms from the accumulation of shell, coral, algae, and faecal debris) with clay and other earth bearing ingredients into a kiln operated at temperatures above 1,300 degrees Celsius. At such high temperatures, the ingredients "sinter" (compact and form a solid mass without melting). This solid mass, in the form of glassy nodules, is called "clinker". After cooling, the clinker is finely ground and mixed with other minerals to produce cement powder.

In its powder form, cement is highly reactive and must be contained to prevent exposure to water. Even vapour in the air is capable of starting the chemical reactions that will (given enough time) return it to a rock-like hardened state.

Portland cement has evolved into numerous types. The most commonly used in concrete manufacture in Australia are~~:~~ General Purpose Grey (GP) and Off White (OW). Other more specialised cements are also used, such as~~:~~ High Early Strength, Low Heat, Shrinkage Limited, Sulfate Resistant, High Alumina, Oil Well and Masonry.

So, what is SCM?

By the 1960's, Australian construction projects were commonly supplementing cement use in concrete with other materials found to exhibit cementitious properties - such as fly ash, slag and silica fume. These materials, known collectively as Secondary (or Supplementary) Cementitious Materials (SCMs) were recognised for improving the durability of concrete beyond that made with Portland Cement alone.

In the beginning SCMs were often far cheaper than cement and available in abundant quantities because they were waste products of other industries keen to relieve themselves of the logistic and financial burden of dealing with their storage and disposal.

Also concrete manufacturing companies were keen to take advantage of ingredients that could potentially replace expensive Portland cement. Furthermore it was clear that SCMs were essential for producing very high strength concretes (80MPa and above). But there was a problem for everyday low grade concretes used in common applications such as slabs, suspended floors and paving.

SCMs are secondary cementitious by nature. Portland Cements are primary cementitious. In simple terms, this means SCMs do not contribute to the set time properties of concrete. Though the long term properties of the concrete are superior, the short term issues for the concrete placer are delays in setting and slower growth of strength. These factors increase project construction time and costs. A commensurate approach to the use of SCMs was adopted by the concrete manufacturing industry to optimise the benefits whilst managing the limitations. What follows is a brief explanation of each of the three most commonly used SCMs in Australia.

Fly ash is a by-product of coal combustion in power stations. It improves the overall performance and quality of concrete. It affects the plastic properties of concrete by improving workability, reducing water demand, controlling bleeding, and lowering heat of hydration. It increases strength development at later stages of the cure, reduces corrosion of reinforcing steel, and generally improves resistance to chemical attack and mobility through a reduction in permeability. Over the last 20 years, current practice has developed to a stage where over 90% of concrete placed contains some proportion of SCM, of which fly ash is the most commonly used, forming the benchmark of Normal Class Concrete, which in turn is defined under AS1379 as a standard type of concrete suitable for most applications.

Ground granulated blast furnace slag (GGBFS), or more simply known as slag, is produced using molten iron slag (a by-product of iron and steel making) from a blast furnace, and quenching it in water to produce a granular product that is then dried and ground into a fine powder. It is typically used in concrete requiring a lower heat of hydration, and where aggressive ground water and adverse environmental conditions are present. As with fly ash blends, early age strength development is slower than with straight Portland cement concrete. However strength development from 28 days onwards is equivalent or better. Another benefit is its colour. It is a very light (almost white) powder that is well suited for specialist decorative projects, particularly when combined with white or off-white Portland cement.

Silica fume, also known as condensed silica fume or micro-silica, is a finely divided residue resulting from the production of elemental silicon or ferro-silicon alloys, that is carried from the steel blast furnace by exhaust gases. Silica fume is often used, with or without fly ash or slag, to make high strength concrete. It was the last of the three SCMs discussed here to be developed and successfully used in concrete. Its mainstream use is as recent as the 1980s. It is commonly the favoured SCM for producing marine grade concrete, or for low-rebound high performance shotcrete.

Over time the more widespread use and dependence upon these materials has driven up the price and eroded the substantial price differences that once existed with Portland cement.

Nowadays the environmental movement and concern over the impact of human development on the planet continues to drive the use of SCMs in concrete.

In 2012 the Australian Government introduced a carbon pricing scheme. Cement producers were identified as large scale polluters, due primarily to the operation of their kilns. It was estimated that for every tonne of cement produced, on average a similar amount of CO_2 is released into the atmosphere.

Though the scheme was repealed in 2014, a lasting consequence was to publically draw attention to industries with the greatest impact on the release of carbon pollution. In raising the awareness of pollution generated by cement production, there has been greater acceptance and demand for the use of SCMs in reducing the quantity of Portland cement used in everyday concrete.

The Green Star Scheme is one of many rating systems designed to encourage and recognise the reduction in greenhouse gas emissions, resource use and waste. The scheme is based on awarding credit points for compliance with specific criteria.

The arm of the scheme that deals specifically with concrete is titled 'Mat-4 Concrete'. It addresses all concrete used in a project including structural and non-structural elements. Up to two credit points are available where the Portland cement content in all concrete used on the project has been reduced by replacing it with supplementary cementitious materials:

• One point is awarded where the Portland cement content is reduced by 30%.
• Two points are awarded where the Portland cement content is reduced by 40%.

More recent developments in the production of concrete, without any Portland cement at all, suggest that the Green Star criteria do not go far enough. But availability of these new generation products, termed Geopolymer concrete, is limited to specific concrete manufacturers producing under licence to the owners of the technology. The technology is based on the commercialisation of proprietary chemicals that chemically activate SCMs and enable them to perform more like primary cementitious materials such as Portland cement.

Population growth perpetually increases demand for concrete and other resources. Reducing or eliminating Portland cement with SCMs makes very good environmental and economic sense. SCMs are, for the foreseeable future, the way of the future.

By Joe Pietrosanto
Vic Mix Pty Ltd