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Abstract

Cement production is a capital intensive business, manufacturing a product that has to meet stringent New Zealand and International Standards. The material is traded between countries and is used in applications regulated by the New Zealand Building Code. Any changes to reduce its embodied energy and its carbon footprint must therefore be well tested and discussed with all affected parties before those changes can be made. Change, when it does occur, tends to be incremental but with transformational change as new technologies are proven and as funds are available.

Fletcher Building Ltd has a commitment to provide high quality building products to the New Zealand building industry and to do so safely, with the least possible impact on our environment. The first steps towards more efficient cement production were taken in the 1960's with the primary aims of to ensuring quality and reducing operating costs. Following that consolidation phase, the focus was on energy efficiency and then post-Kyoto, has been on a progressive reduction in greenhouse gas emissions. The current focus is on recycling and the conservation of resources, without losing the gains in energy efficiency and reductions in carbon dioxide emissions.

With cement produced as efficiently as possible, the Concrete Industry and Design Professionals are able to turn their resources to ensuring that the country's buildings and infrastructure, measured over their lifetime, have the least possible impact on the environment. The industries may be seen by some as slow to change, but they do listen to public opinion and they do react.

1.0 Introduction

Concrete is the world's most widely used man-made material. Society consumes some 12 billion tonnes annually – a cubic metre for every person on the planet (Sakai, 2009). With this leadership role, the global concrete industry recognizes that it must take a responsible position, or face legislation to reduce its environmental impacts.

The science is simple: weathered rock (clay) rich in aluminium and silicon, is fused with sea shells (calcium carbonate) to form “clinker” which is then ground to produce cement. In terms of resource depletion, our Planet is still actively making both of those key ingredients. Mixed with sand, aggregates and water, Portland cement makes Concrete. An increasing variety of waste products are now becoming available to turn into alternative concrete aggregates and cement extenders as the industries seek more sustainable solutions.

The broad sustainability issues which the world-wide cement and concrete sectors have been addressing since the final decade of the 20th Century are:

- Global Warming
- Resource Depletion
- Waste Disposal

A short list, but one that covers big issues; and ones that can only be tackled by concerted international efforts on a number of different fronts.

Each point in the cement and concrete supply chain (including the Architects and Engineers who are designing structures) must play their part in ensuring that, over its economic lifetime a concrete building, bridge, tunnel, airport, wharf or road will have a net positive benefit on our planet in terms of its carbon footprint, its embodied energy compared to its operating energy savings, and its overall effect on the environment. It must also be well integrated into its environment. Fortunately this is relatively easy to do, but popularity comes with a price: the global average carbon footprint of cement has been reduced by 27% since 1990, but world demand for cement has kept increasing (Sakai, 2009) – at least until the recent financial hiccup. The Cement and Concrete Industries readily acknowledge their need to continually seek improved environmental solutions for the construction sector. Fletcher Building Ltd participates in the global Carbon Disclosure Project, an independently audited programme that monitors year by year improvement in such key parameters (www.fletcherbuilding.com).

2.0 Energy Efficiency

The high cost of energy encourages most cement manufacturers to maximize their energy efficiency. Modern plants, such as the Golden Bay Cement plant at Portland, use a dry process that eliminates the energy-intensive drying stage, and use captured heat from the clinker cooling grate to dry and pre-calcine the raw materials before they go into the kiln. Included in that raw feed are fluxing compounds (Mill scale – a waste product from steel rolling mills) which cause the clinker to fuse at a lower kiln temperature. Dry process cement production, combined with pre-calcination of the raw feed, using waste heat; and the use of appropriate fluxing compounds are the main reasons why there has been such a dramatic reduction in the embodied energy and carbon footprint of cement globally, since the Kyoto Agreement on climate change. However every cement plant is different so anyone doing an LCA on Concrete should check the figures for the cement that will be used.

3.0 Raw Materials

A key moral point in the sustainability of concrete structures is that they can be made from local materials, avoiding the high “material miles” associated with imported building materials.

International trade agreements prohibit the use of environmental considerations as trade barriers, but common sense seems to rule in favour of concrete for most major projects.

Cement-making minerals (clay, silica, iron oxide and limestone) are the products of natural processes and are distributed evenly around the world. The early cement producers preferred to base their factories near a source of ‘Cement Rock” - a natural mixture of clay, silica and limestone that could be fed straight into the kiln. Modern cement manufacture usually demands tighter control over the clinker composition, so ‘cement rock’, where it is used, must be supplemented with purer limestone or extra clay and iron to get the optimum chemistry. Sea shells from the local permaculture industries, work well as a source of purer limestone where they are available in sufficient quantities.

Some of the most abundant elements on our planet are those near the top of the Periodic Table; silicon, calcium and aluminium. Almost any naturally occurring minerals containing these elements can be used to make cement, including volcanic ash as a source of silicon and aluminium.

4.0 Fuel

The best rotary kiln fuels are compact, with a high calorific value – coal or used tires are ideal. The long kiln retention time and the high combustion temperature mean that volatile compounds are completely burned and any heavy metal residue, or ash, is fused into the clinker.

Around the world, cement kilns burn a variety of fuels; from waste oil, to animal carcasses and sewage sludge. Society has decreed that those materials need to be eliminated from the waste stream, and that cement kilns (where they are available) are the safest way to do that. Golden Bay Cement burns up to 23% of wood-waste in its Whangarei kiln. This waste comes from timber processing industries in Northland, and from construction and demolition waste out of the “Urban Forest” of Auckland. The advantages of disposing of these wastes in a cement kiln are that residual ash and heavy metals from treated timber become fused into the clinker.

Under the Kyoto Protocol, wood-waste is a carbon-neutral bio-fuel. Left to rot it would form methane, with 23 times the global warming effect of carbon dioxide. Wherever alternative fuels are burned, stack emissions are monitored and the cement manufacturers are constrained to operate within the limits of their local resource consent.

5.0 Non-kiln Mineral Additions

The New Zealand Standard for **General Purpose Portland Cement** (NZS 3122) currently allows this product to contain up to 5% of mineral filler, or pozzolan. This is low by world Standards, so the NZ Portland Cement Association has requested that the NZ Standard be changed to allow up to 10% of mineral addition (Freitag, 2009). But this Standard change process takes time: time to allow the proposed new formulation to be well-tested, and for users and specifiers of cement to understand that the safety or durability of their structures will not be adversely affected. That change process for Cement and Concrete is underway, but the New Zealand building industry is very wary of the $11 billion consequences of Leaky Building

Syndrome, which occurred when those normally rigorous checking processes were by-passed to assist the timber industry.

5.1 Waste Materials as Fillers

Internationally, a number of pozzolanic waste materials are used to improve the sustainability of concrete. The most widely known of these are Fly Ash, from coal-fired power stations; and ground, granulated blast furnace Slag, from steel-making.

In New Zealand we have limited supplies of fly ash from Contact Energy's Huntly power station. This is an excellent "Class C" fly ash when it is available, but Contact Energy restrict the times that Huntly station burns coal, as their contribution to providing more sustainable power to the country's national power grid; and to meet the nation's take-or-pay obligations to the developers of some of our natural gas deposits.

A similar problem exists with slag. Both Pacific Steel and BHP New Zealand Steel, produce slags with the wrong chemistry to achieve pozzolanic activity with Portland cement. Pozzolanic slag for use with cement is therefore all imported. The BHP New Zealand Steel slag is however a suitable source of calcined limestone, and as such can be mixed into the raw kiln-feed at GBC's Portland works. It is used to lower the greenhouse gas emissions and energy demand of Golden Bay's cement production. This contribution is accounted for in the Carbon Disclosure figure that Fletcher Building Ltd submits for the benefit of environmentally aware investors.

Powdered glass is a possible substitute for fly ash and slag, but grinding glass to a particle size of less than 25 microns (where it becomes pozzolanic) is an energy intensive process, which defeats the purpose of specifying it.

5.2 Natural Pozzolans

New Zealand has scattered deposits of natural pozzolans. Historically, Pumicite and Diatomaceous Earth have been used to reduce the heat of cement hydration in major concrete dams, but the only deposit that is currently being worked is the geothermal microsilica deposit at Rotokawa. This product is marketed under the brand of Microsilica 600, by Golden Bay Cement (www.microsilica.co.nz).

Microsilica 600 is an amorphous silica material with a strength efficiency three times that of cement, when it is substituted at dose rates of up to 12% of the cement weight. MS 600 is primarily used to enhance the chemical resistance of concrete and to modify its rheological characteristics. It finds applications in structures requiring high marine durability, or water tightness; abrasion and acid resistance; and improved adhesion, in shotcrete. In terms of sustainability, Microsilica 600 ensures a long, maintenance-free life for our infrastructure and our agricultural industries; and it enables increased labour productivity on job sites where it is used to influence the fluid concrete rheology.

6.0 Milling

The process of grinding clinker to produce cement can be done in a number of ways, but tight control of both the ground particle size and the particle size distribution are important if a manufacturer needs to maximize the performance of pozzolanic fillers in the cement. Golden Bay Cement uses closed-circuit ball mills to produce cement particles within the tight bands required for optimum performance.

An essential ingredient for reducing the milling energy is the Grinding Aid – a proprietary chemical product that increases the grinding efficiency and activates the surface chemistry of the finished cement to enhance its performance. Advances in these products have made a significant contribution to the sustainability of modern cements.

7.0 Alternative Binders

The popular science literature regularly reports news of imminent breakthroughs of alternative cements that promise impeccably green credentials. On closer examination, these are usually based on scarce resources that require extensive processing, or are unproven in terms of their durability and long-term strength. In Structural Engineering terms, load-carrying dependability, structural reliability and long-term durability are paramount in any building products. Golden Bay Cement has been at the forefront of proving alternative binder technology in New Zealand, but to date, the best inorganic chemists in Australasia have been unable to provide the answers that we need to safely market well-proven alternative cements (Harper, 2003).

7.1 Geopolymers

More correctly called Inorganic Polymers; these cements make use of the fact that the next elements in the Periodic Table after Carbon and Hydrogen, that will form strongly bonded polymers under the right conditions, are Silicon and Aluminium. Enthusiasts point to the fact that this is the technology that several ancient civilizations had used to make “artificial stone”. Surely 4000 years of resisting gravity is proof of their durability? Unfortunately those early-use applications were unreinforced. Modern applications of geopolymers require steel reinforcement, but an undesirable property of the polymerization reaction is the release of water, which makes these concretes very permeable.

If the reinforced concrete is not durable, the life cycle analysis does not compare favorably with conventional concrete - except for those rare applications where conventional Portland cement concrete has a very short life. Geopolymer concretes are proving to be cost-competitive in some of those limited applications where their unique properties are an advantage.

7.2 Magnesium Cements

These cements offer energy savings because they calcine at a lower temperature and they absorb back the calcining CO_2 emissions as they hydrate, at a faster rate than calcium compounds do. Unfortunately, suitable magnesium-based deposits are not as widely spread around the planet as limestone is, so transport considerations can offset any savings from the use of magnesium compounds.

7.3 Alkali-activated Materials

These material offer the best global potential in areas where suitable steel mill slag or thermal power station coal ash are readily available. They have a long history of structural use in the Ukraine, going back some 60 years, and the science is much easier to explain than Geoploymer chemistry. Unfortunately, in a carbon-constrained world there is a decline in steel production and an increase in concrete construction with its consequent demand for supplementary cementitious additives to make more sustainable concrete. As a consequence there is not enough suitable precursor materials to produce this type of concrete in the quantities required, or at the locations where it is needed.

8.0 Waste Reduction

The final plank in the sustainability solution is the reduction in waste that is needed to improve the image of concrete. Waste disposal fees are already driving the right outcomes here. Land fill capacity is measured in cubic metres, but charged for in tonnes: every tonne of concrete going to landfill subsidizes the tipping fees of other lighter construction waste. Rather than argue a losing cause, the concrete industry eliminates waste wherever it is able and recycles what it can.

The concrete industry has been accused of “down-cycling” its waste, when demolished concrete structures are crushed to recover the reinforcing steel and to produce hard-fill for road bases or general fill. But the science driving this form of recycling is that calcium ions have such a strong affinity for CO_2 that most calcium compounds (including hydrated cement) are broken down by atmospheric CO_2 as the calcium minerals revert to their preferred calcium carbonate form. This natural “carbonation process” is termed re-absorption, or sequestration, and Engineers must design their concrete mixes (and structures) to ensure that carbonation will not compromise the performance of the structure during its useful life. Beyond that design life, a structure will usually be too expensive to maintain, so demolition and rebuilding becomes the most practical option. When aged concrete is crushed to recover the valuable reinforcing steel, the re-absorption of some 20% of the emitted CO_2 from cement production occurs very rapidly, even if that recycled concrete is going into a road base (Dayaram. 2009).

9.0 Applications Which Exploit Concrete’s Sustainability

Given a range of cements which comply with the relevant New Zealand Standards (containing the lowest embodied energy and smallest carbon footprint that the manufacturer can produce) there is still much more that a concrete producer and a competent team of building professionals can do to achieve even more sustainable concrete structures:

9.1 PaintCrete^{R}. Some 20% of the paint sold in New Zealand never reaches the surface that it was intended for. Most of that left-over paint is now collected under a very effective product stewardship campaign run by Resene. 3R Group collects that returned paint from the Resene Colour Centres (and others in the Paint Wise scheme) and prepares it for other uses. Much of the water-based latex and acrylic paint is suitable for use in Concrete. It is a curious coincidence, that a mix of left-over paint from a large enough market will be “concrete grey” in colour. Those returned water-based paints contain very useful surfactants and polymers, along with fine pigments and fillers which combine to enhance the rheological properties of fresh concrete. Block-fill, for grouted masonry walls is one such application where the waste paint improves the performance and enhances job-site productivity (Haigh, 2008). The waste paint is eliminated from landfill and the end products (Reinforced Concrete Masonry walls) are improved.

9.2 GlassCrete. Waste glass has become a problem for many New Zealand municipalities. The curbside recovery works well, but there is only one re-cycler – in Auckland. The high cost of freight often precludes reprocessing to bottles as a viable option. Crushed glass can however make a useful aggregate for concrete if precautions are taken to prevent the destructive alkali-aggregate reaction that can occur between glass and cement (Slaughter, et. al., 2009). The product, GlassCrete, is suitable for municipal footpaths and cycle-ways; or it can be polished for use as a floor where the thermal mass effect can give homes that are warm in winter and cool in summer, without the need to operate heat pumps.

9.3 Ultra-high Performance Concrete. This new type of structural concrete, with very high cement contents, has been recognized for its sustainability credentials. Although it may have in excess of 700 kg of cement per cubic metre, structures built from it have very slender sections of exceptional durability. The low volume of concrete, combined with its long life, ensure that UHPC can look very attractive in any life cycle analysis (Sakai 2009).

9.4 Quality Assurance. Quality assured cement production; with the lowest possible manufacturing variability, allows concrete producers to design their mixes with the minimum quantity of cement needed to meet their client's required concrete strengths. The cement producers post their weekly test results on the internet to allow knowledgeable customers the ability to avoid using excess cement in their concrete mixes.

9.5 Cement Blends. Adherence to New Zealand Standards provides an easy route for the building industry to ensure compliance with the New Zealand Building Code, but the Building Code leaves the option open for suitably qualified building professionals to specify alternative materials that may have special properties. One such material is Green Star-rated cement, which requires 20% of the cement binder to be replaced by non-kiln material. This is twice the amount that the NZ Cement Standard permits, so its use needs to be carefully monitored to ensure that construction safety is not compromised, and that the intent of the Building Code is met. Custom cement blends are produced in specialized blending plants, using quality assured procedures to ensure uniformity and consistent structural performance.

9.6 Thermal Mass. The increasing availability of Self-Compacting Concrete, with the superior surface finishes and uniform colour that are possible with this revolutionary new concrete, now enable Architects to confidently expose the thermal mass of a structure (Munn, 2004). With the mass of a concrete structure to absorb or radiate heat as required to moderate the temperature in the building, the demands on winter heating and summer cooling are greatly reduced. This thermal mass effect makes use of the fact that human comfort response to an environment is more governed by radiant heat transfer (65%) than by conduction (35%). Exposing the concrete inside a building can therefore allow the Building Services Engineers to run that building at a lower air temperature, without complaints from the occupants. Over the 60 to 80-year life of a typical building this saving in operating energy more than offsets the embodied energy in the concrete structure.

9.7 Concrete Roads. New Zealand's national roading policy, in opting for the lowest initial cost in our road surfaces, leads our road designers towards the use of flexible pavements. Inherent in the flexible pavement philosophy is the recognition that frequent repairs will be required and the accident rate will increase during resealing. From a sustainability perspective however, there is another serious deficiency with flexible pavements: the ground deflects under the wheel loads of heavy trucks. For most of its journey, a heavy truck will be climbing out of a hole – burning some 15% more fuel than it would if it was traveling on a rigid road.

9.8 Pervious Concrete. This type of concrete allows water to percolate through to replenish the ground water while it traps the contaminants normally found in storm-water discharges from roads and parking areas. In addition to cleaning the runoff, pervious paving can be designed to hold water and reduce peak flows to storm-water drains thereby avoiding the need for expensive new drains. This is becoming a very popular method of handling storm water in many parts of the developed world.

9.9 PRESSS Technology. This design methodology for minimizing the earthquake damage suffered by concrete structures during severe earthquakes, provides very sustainable buildings in seismically active countries like New Zealand (Priestley, 2005). Not only is structural damage minimized during a severe earthquake, business disruption can also be reduced. Developed by Professor Nigel Priestley, at the University of California, San Diego, PRESSS technology is revolutionizing the way the world builds earthquake resistant structures for safer and more sustainable facilities in high seismic-risk regions.

9.10 A-Jacks. Concrete can provide reliable solutions for two of the inevitable consequences of global warming for New Zealand: are a rise in sea level, and more severe storms at our latitude. A-Jacks erosion protection units offer maximum stability for the minimum amount of concrete - compared to any other available system (A-jacks - Wikipedia). For protecting river banks from scour and erosion, small 600mm by 600mm units are stamped out on a masonry block machine. These are placed by hand, layered with a suitable filter medium and covered with topsoil or vegetation. They are invisible until a storm hits, and very effectively keep the river confined to its desired channel. They can replace the unsightly piles of rubble in our river beds, with fish-friendly, stable, natural-looking banks. One of the largest purchasers of A-Jack in the US is their Environmental Protection Agency: a great testament to their environmental credentials.

For coastal protection, the A-Jacks units are sized to suit the calculated storm wave height. Buried in the coastal dunes or foreshore, the A-Jacks do their job when the storm surge hits, allowing the natural looking beach-front to be quickly reinstated, and protecting the property behind the unobtrusive coastal defense.

New Zealand has an aversion to placing pieces of concrete on our river banks and sea coast, but skillfully landscaped, these buried structures, specifically designed for the conditions, can provide practical, invisible solutions to storm erosion; protecting property in a very cost-effective way. It is easy to underestimate the power of water, but A-Jacks provide an engineered solution that has been well tested in some of the severest conditions on our planet. They out-perform boulders and rock groins or break-waters.

9.11 Refurbishment & Strengthening. Skilled niche businesses exist worldwide to strengthen and refurbish concrete buildings. Concrete structures can be economically recycled to cope with the most demanding modern load, acoustic and fire demands.

10.0 Conclusions.

More sustainable cement and concrete production can be likened to a long-distance race with no end. As the science develops, and as new solutions are proven, the changes are made and the new products are introduced to the market. But the innovators in the "market" are continually seeking better options from all suppliers of building materials.

Global opinion, enunciated at forums like the Rio Earth Summit, Kyoto and to a lesser extent, Copenhagen, forms the foci for research initiatives that drive global change. We can argue that the process is too slow, but it is steadily improving construction in manner that poses a low-risk to public safety, or to our economy.

Responsible manufacturers make their production data available to Specifiers and end-users to feed into LCA modeling tools. Those numbers are independently audited and are often used by environmentally concerned, ethical investment syndicates, seeking year-by-year improvement in the performance of the businesses that they invest in. A stable pool of such investors is an asset to any publicly listed company and is one of the reasons that businesses tolerate no compromise with regard to their published environmental statements.

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