ENVIRONMENT DESIGN GUIDE

CONCRETE AND SUSTAINABILITY – SUPPORTING ENVIRONMENTALLY RESPONSIBLE DECISION MAKING

Dominique Hes and Margaret Bates

Concrete is the most widely used building material in the world with many architectural and engineering benefits, but also with a high capacity to improve its environmental performance.

The environmental measures that can be taken also improve the performance and durability of concrete, so it can be a win-win situation. One way of increasing durability and performance of concrete is by substituting a portion of the Portland cement with industrial by-products such as slag, fly ash or silica fume. The use of recycled aggregate is another way of reducing the environmental impact of concrete.

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Impacts are mainly in:
  - Raw material extraction
  - Embodied energy
  - Manufacturing impacts
  - Waste.
- Benefits:
  - Thermal mass
  - Indoor Air Quality
  - Longevity.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Specify high extender concrete – extenders are fly ash, slag and silica fume
- Specify recycled aggregate
- Ensure good practices in laying and curing the concrete
- Use recycled materials as waffle pods (plastic, cardboard and tyres)
- Make good use of the thermal mass by correct insulation and orientation.

Cutting EDGe Strategies

- Specify high extender concrete – depending on the application, levels of 80 per cent can be achieved.
- Use 100 per cent recycled aggregate.

Synergies and References

Relevant Australian Standards:

- AS 3582 *Supplementary cementitious materials for use with Portland cement*:
  AS 3582.1 – *Fly Ash*; AS 3582.2 *Ground granulated iron blast furnace slag*; and AS 3582.3 – *Amorphous silica*
- AS 3972 – *Portland and blended cements*
- AS 2758 *Aggregates and rock for engineering purposes*; and AS 2758.1 – *Concrete aggregates*
- C&CAA T41 – 2002 *Guide to Concrete Construction*, Cement & Concrete Association of Australia
- CIA CPN25 – 1990 *Fly ash and its use in concrete - Condensed silica fume and its use in concrete*
- *BDP Environment Design Guide*: DES 4, DES 5, GEN 3, GEN 12, GEN 16, GEN 21, GEN 22, GEN 29, PRO 1, PRO 2, PRO 9, PRO 16.

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This paper discusses concrete and its constituents and their main environmental impacts, and summarises the options for minimising these impacts.

1.0 INTRODUCTION

This paper will outline the ways in which concrete can be used in a more sustainable manner. It looks at the uses of concrete, concrete products, the environmental impact of concrete and the various ways of minimising these impacts and maximising its performance. The paper aims to provide information that will aid in the decision making process.

Concrete is the most widely used building material in the world with many architectural and engineering benefits. Concrete does have a significant environmental impact, but there is also a high capacity for concrete to be specified in such a way that this is minimised, while adding to the good performance of structures it is used in, as outlined below.

The main benefits of concrete are:

- it is versatile and has many applications
- it is strong
- it provides thermal mass
- it provides durable construction
- it is fire resistant.

Environmental measures can also improve the performance and durability of concrete, to make it a win-win situation. One way of increasing durability and performance of concrete is by substituting a portion of the Portland cement with industrial by-products such as slag, fly ash or silica fume. Using recycled aggregate is another way of reducing the environmental impact of concrete.

2.0 CONCRETE

Firstly, it is important to define the difference between concrete and cement. Concrete is made from a combination of materials including cement, coarse aggregate, sand (fine) and water. 'Cement' is a generic term used to describe a wide variety of organic and inorganic binding agents. The most widely used binding agents are those known as hydraulic cements. Hydraulic cements are finely ground inorganic materials which possess a strong hydraulic binding action that is activated when mixed with water and hardens to give a strong durable product. The most widely used hydraulic cements are Portland cements and their derivatives, blends of Portland cement with other materials such as fly ash, slag and silica fume known as supplementary cementitious materials. (The name 'Portland' cement derives from the patent owner who thought the particular mixture of minerals resembled rock quarried on the Portland peninsula in the south of England.)

There is a long history of use of concrete and cementitious products from ancient Rome through to today. (For a look at Australia's history see Lewis, 1998.) The use of concrete has increased greatly over the last couple of decades. In industrialised countries the use of concrete is 1.7 cubic metres per year per person (Berge, 2000). The following figure illustrates the increase in use of concrete in Australia (figures provided by the Australian Pre-Mixed Concrete Association).

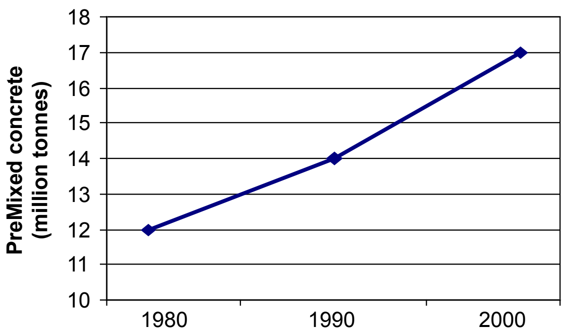

Figure 1. Increase in pre-mixed concrete use

With such a large usage of concrete it is even more important to increase the uptake of resource efficient methods of concrete production and end-of-life treatment. The most obvious ways of reducing the amount of resources used is through recycling of materials. The possibility of using recycled materials and industrial by-products in concrete has been known for decades. There have been some industry barriers to the uptake of new technologies including sustainable concrete solutions. These barriers include habit, lack of training, cost awareness and lack of technical information on applications of new technology leading to concerns about legal responsibilities, such as insurance.

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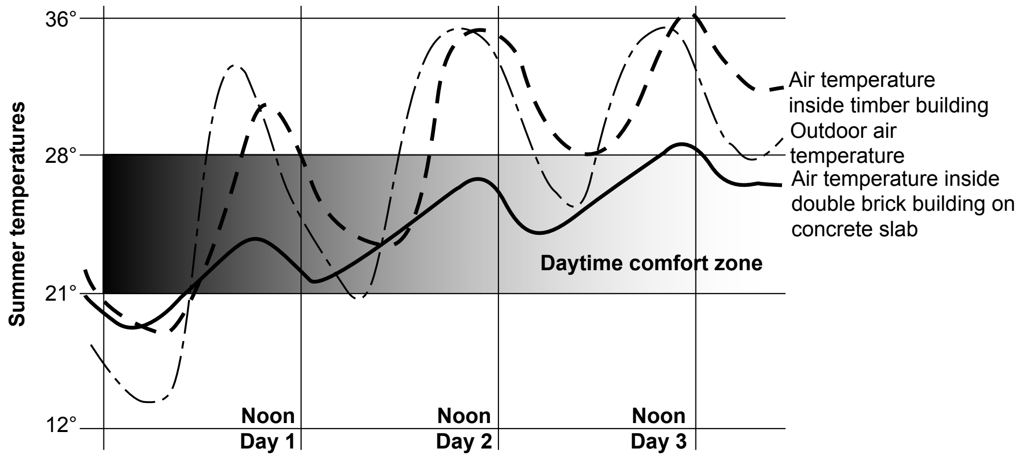

Figure 2. Comparing summer temperatures for buildings of different thermal mass (used with permission from SEAV, 2002)

One of the special benefits of concrete is that it can maintain a particular range of indoor temperature that is most comfortable for the occupants (see Figure 2). This is achieved through its thermal mass and the effective use of passive design. For more information on passive design see GEN 12 and the Cement and Concrete Association of Australia (C&CAA) *Briefing on Passive Solar Design* (2003).

Another benefit of concrete is its positive impact on indoor air quality. Concrete, when exposed internally as structural and non-structural elements e.g. walls, floors and ceilings, is inert and does not give off harmful chemicals when in place. The chemical composition of concrete is void of known carcinogens, such as volatile organic compounds (VOCs) and formaldehydes, and thus does not contribute to symptoms of 'sick building syndrome' which costs UK business around 600 million pounds every year in lost productivity (Glass, 2001).

The reality is that concrete is a fundamental part of the building industry. Many homes are now built on slabs rather than on timber floors and in commercial buildings concrete is used as a major structural element. As the following illustrations show, the applications of concrete in both residential and commercial situations can be both standard practice and innovative.

2.1 Concrete use as building elements

Today concrete is the primary building material for footings, and is often used in construction of walls and retaining walls, beams and columns, roof and floors. Concrete has very good compressive strength properties. However, concrete as a material has inherently poor tensile strength which is normally supplemented by the addition of a steel reinforcement in structural applications.

Figure 3. EcoHome Cairnlea concrete slab (photo used with permission from the Centre for Design)

Figure 4. Commercial applications – 60L use of high extender concrete – see case study for further details (photo used with the permission of 60L Green Building)

One way that concrete is used is in footings (sometimes referred to as foundations) and floors. This is usually in the form of a slab of concrete or slab over footings. Floors and footings for residential buildings are designed in accordance with AS 2870, and for other structures in accordance with AS 3600. The second way is in walling systems where concrete forms the major constituent in tilt-up, in-situ or precast walling systems; concrete brick and blocks; and, in fibre cement sheets. Cement on its own is used as mortar and grout in masonry walls. Thirdly in roofing, concrete is found in tiles. In this element fibres are added to give it its required strength. The tiles are of a relatively low weight and are required to have low moisture absorption so the chemical ingredients of the tiles are carefully balanced. There are issues of damage from heavy hail storms associated with concrete tiles as with the other ceramic-type tiles. Fourthly, concrete is used to stabilise easements and as gravity retaining walls. Concrete is also used in many other small to medium scale applications such as driveways, paths, garden ornaments, guttering and light posts. There are many uses and more are always being discovered and explored.

3.0 ENVIRONMENTAL IMPACTS OF BUILDINGS

To achieve buildings and infrastructure that are more sustainable, we need to reduce overall environmental impacts by reducing emissions and reducing waste. Environmental impacts should be considered in terms of their relative contribution to detrimental effects on global warming, ozone depletion, resource depletion, etc. Although building materials and construction do make an impact it is important to put this into the context of whole of life perspective. The impacts from buildings are mainly from their use (operational): heating, cooling, lighting, hot water system etc (see Figure 5 below). Over the life of a building only about 10 per cent of the total energy is notionally embodied within building materials, the rest is from operational energy (lights, heating, cooling etc). As buildings become more energy efficient, the relative percentage of embodied energy will increase. Embodied energy generally includes extraction, manufacture, transport and construction of building materials.

3.1 Environmental impacts of concrete

Below is a short description of the environmental impacts of concrete. These are summarised in such a way as to easily link to the next section of this paper, which discusses ways in which to minimise these impacts. The main environmental impacts of concrete are through the energy use required to produce the cement constituent parts; resource use; chemical and water issues.

Life cycle issues

As discussed above, when looking at the impacts of concrete and its constituents it is important to take a whole of life perspective as concrete will last many years. From a life cycle perspective the cement constituent of the concrete has the highest impact.

In the production of cement the main life cycle impacts are site disturbance, transportation, production (especially in energy terms) and then the transport to site. Once the concrete is dry there are few impacts, if any. The only documented issue is leaching over time which can occur if the cement is used in concrete which is in a reactive environment.

Below are discussed some of the main impacts of the cement. Briefly back to the life cycle perspective however, it is important to see these impacts in the 50-100 year plus lifetime of the concrete element. From this perspective the longer the concrete application lasts the lower its relative contribution to the overall impact of the construction – operational and maintenance energies being much higher as shown in Figure 5 below (used with permission of the Cement and Concrete Association of Australia).

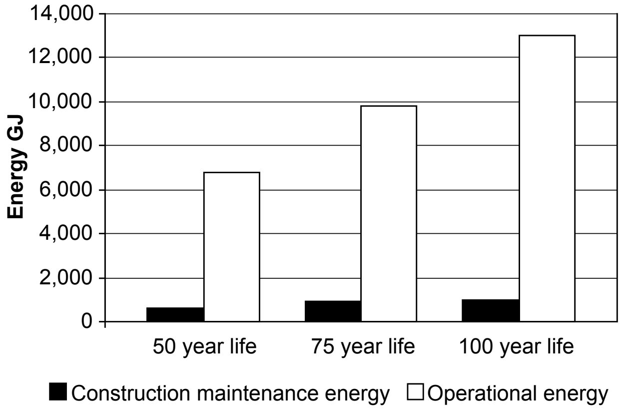

Figure 5. Construction and operational energy over different life spans (adapted from C&CAA, 2003a)

Embodied energy and embodied CO_2

Concrete, cement and steel reinforced cement are often referred to as high in embodied energy. Embodied energy includes the energy used to extract the raw materials and produce the end material. Concrete has a high embodied energy due to high levels of energy consumption in both raw material extraction and processing. Energy use and calcination of limestone result in high levels of CO_2 emissions. The industry usually has high transport emissions due to the weight of the cement. There is also the machinery involved in mining, processing, mixing and pouring.

Energy use

The production of concrete is extremely energy intensive. In fact the cement, concrete and lime industry make up 2.6 per cent of Australia's greenhouse gas emissions, over 1,600 Gg of CO_2 or 1.6 million tonnes (Australian Greenhouse Office, 2000).

The most commonly used cement, Portland cement is manufactured from a carefully proportioned mixture of lime, silica and alumina at temperatures of 1400–1500°C to produce Portland cement clinker. In Australia this dry process is mostly used and is also known as the rotary kiln process. The cement clinker is then ground to produce the cement powder. There is also a wet process which is not as efficient and is known as the shaft kiln process. Apart from the energy related CO_2 emissions, there are also CO_2 emissions released through the calcination process when the calcium carbonate in limestone is changed into calcium oxide.

> Since 1990 there has been a 20 per cent increase in energy efficiency; 13 per cent reduction in total emissions per tonne of product (cement) sold; 4 per cent reduction in process emission per tonne of product sold; 24 per cent reduction in emissions from fuel use per tonne of product sold; 15 per cent reduction in indirect emissions from power use per tonne of product sold (Cement Industry Federation, 2003).

Energy related greenhouse gas emission from the kiln can vary *"depending on the type of kiln and the fuel used. For a 'wet' process… it is near 1.1 tonnes of* CO_2 *per tonne of cement and for a more energy efficient 'dry' process it is of the order of 0.9 tonnes of carbon dioxide per tonne of cement, but a tonne per tonne is a good average."* (Samarin, 1999)

Another issue is the fuel used to stoke the kilns. The kilns are usually fired by coal in Australia but some kilns are supplemented with gas or oil. Some use waste material (e.g. tyres) in the kilns but there is concern about the potential toxicity of the emissions from such fuel. These concerns are addressed by ensuring that the plants meet regulatory emission requirements set out under the National Pollution Inventory.

> In 2002 the Australian cement industry replaced almost six per cent of its thermal energy consumption with alternative fuels. There is potential for the use of alternative fuels to increase substantially, with one plant in Australia – the Blue Circle Southern Cement plant at Waurn Ponds, already meeting some 50 per cent of its thermal energy requirements from alternative fuels (Cement Industry Federation, 2003).

Some facilities have reduced their emissions through energy efficiency improvements and through increased use of waste lime (instead of using more energy to convert limestone to lime). Heat loss from the plants can be harnessed through steam production or electricity. The manufacture of steel and further processing into round or profiled bars and welded mesh which is often cast into concrete, adds significantly to the total embodied energy for conventional reinforced concrete.

Resource use

Concrete production uses a lot of raw materials. Some of the raw materials are plentiful in different parts of the world but they are non-renewable. The mixture of concrete ingredients can generally be adapted to suit the availability of local materials. However, mining of raw materials can produce soil erosion, pollutant runoff and habitat loss.

There is also a significant environmental impact from covering the land with impervious surfaces. It creates a hotter environment with polluting runoff. Land underneath concrete and other impervious surfaces becomes inert.

Chemical impacts

Once cured, concrete is relatively inert. Some literature has highlighted that during the curing process chemical admixtures, curing compounds, and sealers may emit Volatile Organic Compounds (VOCs). However, as most curing compounds used in Australia are water-based this is no longer a significant issue. If the concrete is not adequately hydrated, for example because of insufficient curing afterwards, it can react with other materials such as fillers with organic material and plastic coatings. Some research states that if setting is not effective there can be chemical reactions with neighbouring materials like PVC flooring and that during the drying period of a building organic material touching the concrete can be damaged (Berge, 2000).

Water issues

Water is an integral part of concrete. It produces the hydration reactions in cement which turn the cement paste into a hardened binder. It provides workability/ fluidity to the material, which is one of the main advantages of concrete, as it can then be moulded into any shape. However, there are environmental impacts from the water use because alkaline waste water is produced during production and placement. It is therefore important that concrete production and the building site is managed to prevent run off: it is for this reason that most concrete manufacturing plants have extensive water reuse and recycling processes to ensure no contamination.

> Increasing proportions of cement produced in Australian are from newer dry process technology, which significantly reduces the water consumption per tonne of clinker. Since 1990, the number of wet process kilns in operation in the Australian industry has reduced from twenty to seven, with corresponding clinker production volumes reducing from almost three million tonnes to less than one million tonnes. Wet process plants now account for less than 15 per cent of Australian cement production. In these plants, water is used for the slurry preparation of raw materials. Water is also consumed in the cooling of equipment and exhaust gases. All of the water in the slurry is evaporated during the cement production process but other plant water is normally re-cycled in closed loop systems. There is minimal discharge of water to the surrounding environment from these wet process cement plants. (Cement Industry Federation, 2003)

4.0 MINIMISING THE ENVIRONMENTAL IMPACTS AND OPTIMISING THE BENEFITS OF CONCRETE

The Portland cement and to some extent the reinforcement have the most serious environmental consequences, so it is important to try to choose the most appropriate alternatives whilst also reducing the proportion of the ‘raw’ or virgin ingredients in the concrete.

In this section, the main ways of optimising the benefits of concrete are outlined and alternatives to concrete in the different building elements are also highlighted. On a positive note, concrete recovery has grown by 200 per cent since 1993 with 899,000 tonnes being recovered and reprocessed in the state of Victoria (annual survey of Victorian recycling industries 1999/2000 published by EcoRecycle Victoria, 2001). The majority of the recovered concrete is generated from the demolition sector.

But firstly, it is important to note the basic ratio of materials that make up concrete to put into context later discussion of percentages of added extenders and aggregate.

Cement	10-15%
Water	5-10%
Aggregate	60-80%
Reinforcement	1-6%

Table 1. Typical volume of concrete composition

4.1 Optimising benefits of concrete

The durability and strength of concrete depends on the quality of work and raw materials, as well as the proportions of the mix and the environment the building is sited in. If the concrete is exposed to pollution such as carbon dioxide and sulphur dioxide, the concrete can break down more quickly over time. Both the durability and strength can be enhanced with the addition of fly ash and slag cement. Please note that the term ‘extender’ as used in this paper refers to the addition of an industrial by-product to the cement.

> In 2002 the percentage of cementitious material sold was:
>
> - Fly ash comprised about 15 per cent (1.2 million tonnes of bulk fly ash).
> - Granulated blast furnace slag accounted for nearly four per cent (300,000 tonnes of granulated blast furnace slag)
>
> (Cement Industry Federation, 2003).

Fly ash

Fly ash is the fine powder extracted from the flue emissions of the burning of black coal. It is not cement but a pozzolan and normally ends up in landfill. Used in cement it reacts with the excess calcium hydroxide produced in the Portland cement hydration process, and ultimately produces additional cementitious material (binder). This produces concrete with a higher ultimate strength and durability when used in proper amounts. It has been proven that fly ash improves the durability of concrete. CSIRO has conducted research into the optimal fly ash content and durability for cost. The optimal fly ash content for minimum cost appears to be in the region of 50-75 kg/m^3. Beyond 75 kg/m^3 the cost of the concrete increases. However, the higher the amount of fly ash in the concrete, the greater its durability, depending on the quality of the fly ash (Khatri and Sirivivatnanon, 2001). Silica fume ash can also be used.

Research has shown that volumes of over 25 per cent of fly ash of cementitious material can make it more difficult to achieve the mix of plastic and hardened properties sought. But this does not hold true for adding extra amounts of slag so that the total amount of extended concrete can get as high as 50 per cent such as successfully used in 60L (see Case Study section at end of this paper).

Application	Optimum % of fly ash
Grade 20	28% (cost*)
Grade 50	10% (cost)
chloride and sulphate environment	40%
benign environment	75 to 100 kg/m³
for aggressive environment	150 kg/m³

* optimum cost weight ration, balancing environmental gain and cost of material.

Table 2. Optimum fly ash content adapted from (Khatri and Sirivivatnanon 2001)

An example of reduction in emission levels is, according to Samarin (1999): one cubic metre of good structural concrete, made with 320 kg/m³ of Portland cement only, will produce about 0.41 tonnes of CO_2 emitted into the atmosphere. If 30 per cent of Portland cement is replaced with fly ash, this figure is reduced to about 0.29 tonnes of CO_2 (neglecting of course the CO_2, produced during the combustion process which generated the fly ash).

Blast furnace slag

Blast furnace slag is the by-product of iron manufacture and can be used in cement and concrete to reduce the amount of virgin material used. Blast furnace slag can be used as aggregate. Slag cements are made from ground granulated blast furnace slag. Like Portland cement, slag cement is hydraulic cement: that is, its binding properties are activated when mixed with water. It also reacts with the by-product calcium hydroxide produced by Portland cement which generates more cementitious material. This improves concrete strength and durability when used in proper amounts (see Table 3). The strength of slag cement is good and it has few problems, though research (Berge, 2000) has shown there may be some issues with the fresh mixture not being able to be stored for long periods, and it must therefore be used shortly after production. Slag cements contain 20-40 per cent slag for general construction and 60-70 percent for applications requiring reduced heat for hydration and improved sulphate resistance.

Concrete application	Slag cement
Concrete paving	25-50%
Exterior flatwork	25-50%
Interior flatwork	25-50%
Basement floors	25-50%
Footings	30-65%
Walls and columns	25-50%
Tilt-up panels	25-50%
Pre-stressed concrete	20-50%
Pre-cast concrete	20-50%
Concrete blocks	20-50%
Concrete pavers	20-50%
High strength	25-50%
ASR mitigation	25-70%
Sulphate resistance	
Type II equivalence	25-50%
Type V equivalence	50-65%
Lower permeability	25-65%
Mass concrete	50-80%

Table 3. Optimum use of slag related to purpose (adapted from Slag Cement Association, 2003)

4.2 Recycled aggregate

Usually aggregate is sand, gravel or crushed stone. Virgin aggregate can be partially or wholly substituted by recycled aggregate, depending on the end use of the concrete and the strength requirements. On a recent project in Croydon, Boral used 100 per cent recycled washed aggregate. At specific plants in Victoria, Boral uses about 30 per cent replacement aggregate with reclaimed crushed concrete for slab work with the intention of widening this policy to other plants (personal communication with Pavement Engineer from Boral Concrete).

Recycled concrete aggregate (RCA) is utilised in a broad range of applications including road base, fill and hardstand areas. RCA is priced competitively with virgin product alternatives and can perform as well as, and in some applications better than, conventional product. However, quality control is very important, and problems can occur if the recycling operation does not handle and segregate the product properly. For example, one concern would be contamination with plasterboard from demolition, which can produce sulphate attack in concrete. Also, if the original concrete was of poor quality or was in, say, a sulphate environment, it can have detrimental effects on the new concrete.

RCA is also generally lighter than conventional mixes and therefore provides better value for money (EcoRecycle, 2001). Blast furnace slag aggregate can also be used and makes an excellent lightweight aggregate. There are also thermally insulating or lightweight options. Alternatives include ground concrete or crushed bricks (bricks made of fired clay cannot be used if they contain nitrate residue from artificial fertilisers as this increases the decay rate of the concrete). The important thing is to use material that will not react with lime or degrade over time.

When using concrete as part of a slab of a basement to a house, the chemicals, chemical water treatment and the chemical composition of the aggregate need to be checked. Concrete and its constituent parts is a complex chemical mixture in which some chemicals can react with each other in such a way as to cause weaknesses and provide an access for environmental

Blue Circle	Independent Cement	Alice Roof Tiles
20 MPa strength – 100% recycled aggregate Mixture of recycled aggregate for 30MPa Virgin aggregate for 40 MPa	Generally 60% substitution of cement with fly ash and slag, up to 80% depending on strength required	80% slag content in their concrete tiles. Strength exceeds AS 1400

Table 4. Examples of what some Victorian concreting companies are currently achieving in this area

break down of the concrete. Trial batches of concrete must be produced to check for properties and material compatibility, especially when untried materials or mixtures or combinations are used.

4.3 Concrete reinforcement

Steel is the most common reinforcement in concrete. It is usually made from recycled scrap metal with about 10 per cent new to make it stronger. The reinforcement of concrete using steel comes in many forms. More conventional forms of concrete reinforcement are round or ribbed bars, either loose or welded into square or rectangular mesh sheets. These steels are worked and formed in their manufacture and then manually placed and cast into concrete to reinforce planes of weakness inherent in most concrete elements. Some alternatives include: reinforcement in the form of 15mm long bars or fibres that are placed or mixed in proportions of 1-2 per cent of the volume of the concrete. The reinforcement is there to take up the strain within the concrete and improve the tensile strength of the composite reinforced concrete product. The amount of reinforcement needed can depend on soil, structural loading and slab thickness.

Other fibres have been introduced as reinforcement in recent years such as glass and carbon, polypropylene, wood fibres including bamboo and hemp (Berge, 2000). The main role of these non-steel fibres is during the setting period when shrinkage of the concrete mainly occurs. Fibrous reinforcement fabricated from recycled plastic is available in the USA. However these fibres cannot be recycled and even the smaller steel fibres rather than bars, are difficult to recycle. Separating plastic may require water to float plastic shards. The concrete does not lose its strength if or when the fibres decompose.

4.4 Water issues

Water content in concrete is normally measured as the *water/cementitious* (w/cm) *ratio*, which is the mass of water divided by the mass of cementitious material in a concrete mixture. Generally, the lower the w/cm, the higher the concrete strength and the concrete matrix is more durable and less permeable. However low w/cm also can make concrete less workable and more difficult to place. Chemical admixtures such as mid and high range water reducers can aid workability in low w/cm mixtures.

Usually concrete with fly ash or slag requires marginally less water because these products improve concrete workability. This has the added benefit of allowing the concrete to be produced with a lower w/cm ratio, resulting in higher strength and durability. Fly ash, slag cement and silica fume are generally required to produce 'high performance concrete' which can have very high strength, high resistance to chemical attack, very low permeability, low shrinkage or a combination of these properties.

4.5 Waffle pods and hollow core ventilation

A rather clever way of reducing resource consumption is by casting waffle pod void formers in the slab. This is a common practice in some states such as Victoria. Waffle pods are ideally recycled tyres or cardboard carefully placed to form a close grid of cross concrete beams. The waffle pods are covered in a layer of plastic, then a steel frame and then the concrete is poured on. There are companies that supply the tyres and Ecoflex supplies a similar product made from recycled tyres. There are other products on the market that use polystyrene pods and similar products but without the added benefit of using material that would otherwise be going to landfill. The main benefit of waffle pods is that they reduce the amount of concrete needed for a foundation slab. A concrete waffle pod slab with permanent polystyrene formwork can add to your under slab insulation (*Your Home*, 2003). Waffle pods do not reduce thermal capacity.

An integrative system that requires careful planning for the built and use phase of the building is through the use of concrete planks to build a floor structure, which is integral to the ventilation and temperature of the building. In a hollow core flooring system, air is drawn in from outside or from an atrium or centralised point and then forced through the system of hollow core concrete planks that form the slab floor. They can be used as an energy exchange device and either add or remove heat from the building. There are examples of architects making holes through certain sorts of waffle pods to create these spaces (see Contacts and Case Study sections). Hollow core ventilation is known as an active hybrid system. Any opportunity to maximise or utilise a greater exposed surface area of concrete for improving passive ventilation is of great benefit.

Tips and suggestions:

- When placing concrete adopt good practice to reduce problems mentioned above.
- Specify water-based, zero or low VOC additives, sealers and coatings.
- Verify that the curing compound is compatible with the specified floor sealer or finish. Specify ventilation during placing and curing for interior work.
- Concrete admixtures are now available that retard the setting of concrete so that a partial load of

excess concrete can be returned to the ready mix plant for one to two days and then reactivated for use.

- Cured waste concrete can be crushed and reused as fill or as a base for pavement or aggregate in concrete manufacturing.
- Plant fabrication handling raw materials and by-products at one location allows greater efficiency and better pollution control than job-site fabrication.
- Houses on a concrete slab floor can benefit through the use of polished or tiled floors which enable more heat gain to be stored.
- Most architectural items, such as bollards, can be made with recycled aggregate.
- Concrete units are easier to dismantle and reuse.
- Slag cement and fly ash will tend to increase setting time of concrete mixtures, and decrease early strength, particularly at higher substitution levels and/or during cooler weather. Make sure you have planned for this in your construction loading/form stripping operations/sequencing
- Temporary forms (metal pan forms, wood forms and corrugated paper forms) are generally reusable and easily recyclable. Specify reclaimed wood or sustainably harvested wood for wood forms; FSC (Forest Stewardship Council) approved plantations. Permanent insulating formwork will conserve energy.

5.0 NEW TECHNOLOGIES

In recent years there have been various developments with alternative cements, admixtures and other related concrete products. Most of these are still being developed and tested and many have unverified claims. It is worth having a look at them briefly as they will have an impact in the future.

5.1 TEC ECO cement

John Harrison, the managing director of Tec Eco Pty Ltd in Hobart, Tasmania has invented a new concrete in which reactive magnesia, other hydraulic cements such as Portland cement, pozzolans and aggregates, are blended together. Two main products have so far been developed. Modified Portland cement concretes are claimed to be much more sustainable because of reduced emissions, greater durability and higher waste utilisation. Eco-cement concretes contain higher proportions of reactive magnesia than porous products such as bricks and blocks carbonates, which is claimed to sequester CO_2. With capture of CO_2 during production, the new materials offer enormous potential for environmental gain; combining insulating, thermal capacity and low embodied energy characteristics in a building material utilising a high proportion of wastes (i.e. combination of pozzolans, slag, and mine tailings). Recently, they achieved 42Mpa strength with half the cement content. The product is in the process of commercialisation.

5.2 EcoCem

Expanding on the slag cement discussion above, a new technology in ball milling is allowing the use of greater percentages of slag in cement. The grinding mill at Wollongong and the new process allows for the control of particle size and therefore control over water demand, setting time, compressive strength and strength gain in mortar and concrete (McAlister and Hinczac, 2001). This product is used extensively by companies such as Blue Circle in NSW and Independent Cement in Victoria.

5.3 Geopolymer cement

Geopolymer cement is a lower embodied energy alternative to Portland cement. Rather than using a high temperature cement calcination process, geopolymers can be formed at ambient temperatures, thereby reducing significantly the generation of greenhouse CO_2 gas emissions. In fact, it is claimed that geopolymer technology could reduce CO_2 emissions caused by the cement and aggregates industries by up to 80 per cent (Lukey, 2002).

Geopolymeric products are usually made from waste materials such as fly ash, blast furnace slag, waste concrete, plastic, glass and paper. Geopolymer made products are currently not available in Australia, though there are some research activities (see Hardjito et al, 2003).

5.4 Alkali activated slag (AAS)

Alkali activated slag is a cementitious binder using ground granulated iron blast furnace slag and alkali activator (no Portland cement used). Research on AAS both overseas and in Australia (Sanjayan and Collins, 2002) showed that high early strength can be achieved. However, issues such as high shrinkage and other possible limitations or constraints to the application of the material are under investigation.

6.0 CASE STUDIES

6.1 Green building with concrete using extenders and recycled aggregate

Architect: Spowers Architects

Structural Engineers: JMP Consulting Engineers

60 Leicester St, Carlton – the 60L Building

60L was built to be a model green building, which is occupied and run commercially. Tenants are committed to a ‘green’ tenancy agreement and the feedback so far is very positive. Initially, the building was designed with a complete timber framed structure for the new three-storey extension. Reinforced concrete was finally adopted due to the thermal mass benefits and significant savings in the whole of life energy use of the facility.

In terms of on-site experience with specifying and delivery of sustainable concrete solutions, the experience of site managers was positive. This project pioneered the use of cement sourced from a high efficiency dry kiln with 60 per cent fly ash and blast furnace slag content. This cement has an embodied energy content and greenhouse impact at least 50 per cent below the Australian average (Pears, 2003). The problems feared by contractors did not eventuate.

Very high proportions of cement substitutes (in excess of 50 per cent) were specified for all concrete grades for the building structure. One hundred per cent recycled concrete aggregate was also specified.

An initial concern during the construction phase was that as part of the specification nominated no additives or admixtures in 20 and 25 MPa grade concrete, whether it would pump as well without admixtures and with high extender content. In practice there was no problem with the pumping, placement and finishing. Generally concrete pumps better with fly ash or slag cement content.

Another concern had been with the recycled concrete aggregate. Measures were implemented to screen out lumps, which initially formed in the pre-mixed concrete delivered to site due to partially hydrated recycled concrete aggregate, which worked very effectively.

Whilst initially the building contractor, concrete suppliers and concrete sub contractors were curious about this new 'green' concrete, once familiar with it, working with the concrete became routine.

For more information see the 60L website http://www.60lgreenbuilding.com.

6.2 Hollow core flooring

Architect: Eggleston Macdonald Design Inc

Structural Engineers: Meinhardt (Vic)

Commercial application

Project: Faculty of Science and Technology Building T, Deakin University, Burwood, Victoria

Hollow core flooring is widely used in Scandinavia, Europe and Japan. Building T at Burwood is one of the earliest examples of such a flooring system being used in Australia. The design team included structural and engineering consultants, a consulting architect and representatives from Deakin University's Building and Grounds division. The system used in the flooring is known as Termodeck and uses the planks (longitudinal voids) in the Hollow Core system to circulate air through to alter the internal temperature. The planks used were 200mm wide and the 'holes' were 150mm in diameter. Careful computer modelling was undertaken to explore the relationship between the thermal mass and air flow requirements. The end result was a building with a central atrium and three-storey concrete frame to provide as much natural lighting and ventilation as possible.

6.3 Concrete Flooring and Tilt up Walls

Architect: de Campo Architects

Structural Engineer: Bruce Adams Consulting Engineers

Domestic application – Toorak, Victoria

Building type: Semi-attached, three level

The main element of interest here is the use of a Thermomass tilt-up walling system and hollow core planking system. The Thermomass system is basically a system of insulated concrete sandwich panels which provide quick installation and high thermal mass. The Thermomass system has an inner layer of 150mm concrete, then 50mm of styrofoam insulation and an outer layer of 65mm concrete. It is tied together with composite thermal connectors.

The Hollow Core system in this application formed the floor/ceiling/roof slabs. The hollow core concrete slab was used as the main structural unit in the ceiling with a waterproof membrane and a layer of polystyrene tied to the wall planes to maintain a thermal envelope.

(Information for the last two case studies are drawn from C&CAA *MIX*, January 2003.)

7.0 CONTACT DETAILS FOR MANUFACTURERS

7.1 Products and Suppliers

Alex Fraser *Recycled Crushed concrete and/or aggregate*
03 9369 7388 www.alexfraser.com.au

Alice Roof Tiles
03 5367 6212 www.barro.com.au

Australian Steel Mill Services *Slag producers and reprocessors EcoCem recycling plant*
02 4276 2288

Blue Circle Southern Cement *Slagmen; EcoCem (NSW); Recycled crushed concrete and/or aggregate*
03 5241 8291 www.bluecirclesoutherncement.com.au

Boral *Envirocrete (mainly suitable for pavements, commercial sites, slab preparation and car parks). Recycled crushed concrete and/or aggregate; Formply*
1300 650 564 www.boral.com.au

Carter Holt Harvey *Formply*
07 3902 7400 www.chh.com.au

Composite Systems *Thermomass, tilt up slab system*
03 9824 8211 www.compositesystems.com.au

CSR Hebel *Aerated Autoclaved Concrete*
1300 369 448 www.hebelaustralia.com.au

CSR Gyprock *Fibre Cement plasterboard*
1800 678 068 www.gyprock.com.au

Ecoflex *Recycled tyre product – also make retaining walls*
02 4940 0178 www.ecoflex.com.au

Hollow Core Concrete
03 9369 4944 www.hollowcore.com.au

Independent Cement and Lime *Blended Cement: EcoCem (Vic)*
03 9676 0000 www.independentcement.com.au

Island Block and Pavers *Using TecEco in some pavers*
03 6398 2088 www.islandblock-paving.com.au

Local Mix Concrete *Premix concrete, Recycled crushed concrete and/or aggregate*
03 5250 1666

Minibah Recycling *Recycled tyres*
03 8790 1927 www.minibah.org.au

Neumann Steel *Recycled tyres Full waffle pod system*
07 5589 9111 www.neumann.com.au

Pronto Mixed Concrete *Slag blend*
03 9663 1333 www.barro.com.au

Smorgons ARC *Recycled steel*
03 9360 2473 www.smorgonsteel.com.au

TEC ECO
03 6271 3000 www.tececo.com

Termodeck *(used by Hollow Core)*
www.termodeck.com

7.2 Industry contacts

The Ash Development Association of Australia

Australian Pre-Mixed Concrete Association

Australasian Slag Association

Cement and Concrete Association of Australia

Cement Industry Federation

Concrete Institute of Australia

8.0 RELEVANT AUSTRALIAN STANDARDS

AS 3582 *Supplementary cementitious materials for use with Portland cement*

AS 3582.1 – *Fly ash*

AS 3582.2 – *Ground granulated iron blast furnace slag*

AS 3582.3 – *Amorphous silica*

AS 3972 – *Portland and blended cements*

AS 2758 – *Aggregates and rock for engineering purposes*

AS 2758.1 – *Concrete aggregates*

9.0 RELEVANT NOTES

DES 4 *Thermal mass in building design*

DES 5 *Architects and ecologically sustainable design: A client briefing*

GEN 3 *Biodiversity and the built environment*

GEN 12 *Residential passive solar design*

GEN 16 *An overview of environmental assessment management tools*

GEN 21 *Waste minimisation and waste recovery*

GEN 22 *Life cycle energy analysis: A measure of the environmental impact of buildings*

GEN 29 *Waste minimisation and building design professionals*

PRO 1 *Assessing the environmental impact of building materials*

PRO 2 *Embodied energy of building materials*

PRO 9 *Recycling building materials*

PRO 16 *Introduction to building material sustainability*

REFERENCES

Alcorn, JA and Baird, G, 1996, *Use of Hybrid Energy Analysis Method for Evaluating the Embodied Energy of Building Materials*, WREC.

Australian Greenhouse Office, 2000, *Australia's National Greenhouse Gas Inventory 1990, 1995 and 1999 end use allocation of Emissions*, Australian Greenhouse Office, Canberra, http://www.greenhouse.gov.au/inventory/enduse/pubs/vol1-enduseanalysis.pdf, last accessed 29/5/03.

Berge, B, 2000, *The Ecology of Building Materials*, Architectural Press, Oxford.

Buchanan, AH and Honey, BG, 1994, *Environmental Impacts of the New Zealand Building Industry*, in Energy and Buildings, Vol 20, pp205-217.

Cement & Concrete Association Australia, 2003, Briefing Note - *Passive Solar Design*, Cement and Concrete Association of Australia, http://www.concrete.net.au/search.php?publication=free&menu=7, last accessed 29/5/03.

Cement and Concrete Association of Australia, 2003a, *Life Cycle Assessments of Buildings in Australia – Case Study Detached House*, http://www.concrete.net.au/Life_cycle/case_studies/DetachedHouse/5-7-1.php, last accessed 29/5/03.

Cement and Concrete Association of Australia, 2002, *Passive and Active Hybrid Systems*, MIX, Volume 10, July 2002, pp4-5.

Cement & Concrete Association of Australia, 2002, *T 41 Guide to Concrete Construction*, Cement and Concrete Association of Australia.

Cement and Concrete Association of New Zealand, 2003, *Admixtures*, http://www.cca.org.nz/mat_prop/admixtures.htm.

Cement Industry Federation, 2003, *Environmental Report*.

EcoRecycle, 2001, *Concrete, Bricks and Asphalt*, www.ecorecycle.vic.gov.au/www/default.asp?casid=2920, last accessed at 20/07/03.

Federal Energy Management Program, 2003, *Greening Federal Facilities*, Department of Energy (Energy Efficiency and Renewable Energy Network) USA, http://www.eere.energy.gov/femp/techassist/over_green.html, last accessed 29/5/03.

Glass, J, 2000, *Fabric Energy Storage with Precast Concrete*, Oxford Centre for Sustainable Development, Oxford Brookes University.

Glass, J, 2001, *EcoConcrete: the Contribution of Cement and Concrete to a More Sustainable Built Environment*, British Cement Association, Crowthorne, UK, 2001.

Glover, J, 2001, *Which is Better? Steel, Concrete or Wood: A Comparison of Assessments on Three Building Materials in the Housing Sector*, Department of Chemical Engineering, University of Sydney: Sydney, http://www.boralgreen.shares.green.net.au/research3/chap3.htm, last accessed 29/5/03.

Hardjito D, Wallah, S and Rangan, V, 2003, *Properties of Geopolymer Concrete with Fly Ash as its Source Material*, Paper presented at the CIA Biennial Conference, Brisbane, July 2003.

Harrison, J, 2003, *The TecEco Times*, Newsletter 26, May 2003, www.tececo.com, last accessed 29/5/03.

Institute of Civil Engineers, 1985, *Improvement of Concrete Durability*, Thomas Telford, London.

Khatri, RP & Sirivivatnanon, V, 2001, *Optimum Fly Ash Content for Lower Cost and Superior Durability*.

Kwok, G, (ed) 2001, *Concrete Panel Homes* Handbook, Cement and Concrete Association of Australia.

Lawson, B and Royal Australian Institute of Architects, 1996, *Building Materials, Energy and the Environment: Towards Ecologically Sustainable Development*, Red Hill, ACT: Royal Australian Institute of Architects.

Lewis, M, 1988, *200 Years of Concrete in Australia*, Concrete Institute of Australia.

Lukey, GC, 2002, *Geopolymer Technology - Concrete Of The Future?* Environmental Engineer, Journal of the Environmental Engineering Society, Institution of Engineers, Australia, Vol 3 No 3 Spring 2002: pg5.

McAlister, G and Hinczac, I, 2001, *Ecocem – A boon for the environment*, Connections - The Australasian Slag Association newsletter Volume 2, Issue 3 September 2001.

McGraw-Hill, Vale, B & Vale, R, 2000, *The Autonomous House*, Thames and Hudson.

Munn, C & Gjerde, M, 2002, *Building Comfortable Homes*, Cement and Concrete Association of New Zealand & Energy Efficiency Conservation Council.

Pears, A, 2003, *Commercial Building Energy Efficiency: Lessons from 60L and Other Recent Projects*, paper presented at Business Council for sustainable energy annual conference, Sheraton Hotel Brisbane, April 2003.

Phelan, WS, 2000, *Admixtures and Aggregates: Key Elements of Athletic Concrete*, Euclid Chemical Company, April, http://www.euclidchemical.com/elit/admixtures.pdf.

Phillips, RO, 1992, (6th Edition) *Sunshine and Shade in Australia*; Technical Report 92/2, CSIRO Division of Building Construction and Engineering.

Roaf, S, Fuentes, M & Thomas, S, 2001, *Ecohouse: A Design Guide*, Architectural Press.

Sagoe-Crentsil, T, Brown & Taylor, A, 1998, EcoRecycle Market Development Grants Program: Field demonstration project: *Construction of building and recreational facilities with recycled concrete*: Final Report, EcoRecycle, www.ecorecycle.com.

Samarin, A, 1999, *Utilisation of waste from coal-fired power plants - an important factor in the abatement of greenhouse gas emissions*, in ATSE Focus, (106), http://www.atse.org.au/publications/focus/focus-samarin2.htm, last accessed 29/5/03.

Sanjayan J and Collins, F, 2002, *The challenge of the cement industry towards the reduction in greenhouse emissions*, Paper presented at the International Association for Bridge and Structural Engineering (IABSE) Conference, Melbourne, May 2002.

SEAV, 2002, *Thermal Mass*, Energy Smart Housing Manual. Melbourne, Sustainable Energy, A, 2003: 36-41.

Shaeffer, RE, 1992, *Reinforced Concrete: Preliminary Design for Architects and Builders*, McGraw Hill College, New York.

Slag Cement Association, 2003, *Proportioning Concrete with Slag Cement*, Slag Cement Association, http://www.slagcement.org/proportioning.htm last accessed 29/5/03.

Slag Cement Association, 2003, *Proportioning Concrete with Slag Cement*, Slag Cement Association, 2003.

Slattery, K & Guirguis, S, 2001, *Life Cycle Assessment of Buildings in Australia*, Cement and Concrete Association of Australia.

Spiegel R & Meadows, D, 1999, *Green Building Materials: a Guide to Product Selection and Specification*, John Wiley & Sons, New York.

Sustainable Energy Authority Victoria, 2002, *Thermal Mass, in Energy Smart Housing Manual*, Sustainable Energy A, Melbourne, pp36-41.

Thomas G & Donn, M, 2001, *Designing Comfortable Homes*, Cement and Concrete Association of New Zealand & Energy Efficiency Conservation Council.

YourHome, 2003, http://www.greenhouse.gov.au/yourhome/technical/fs16b_8.htm.

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