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BRIDGING THE GAP BETWEEN ENGINEERING PRACTICE AND ACADEMIA: A MATERIALS SUPPLY PERSPECTIVE

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ABSTRACT

Since commencement in 1967, the ACMSM series of conferences has targeted contributions in materials research, structural analyses, computational studies and foundation engineering, all fundamental to engineering practice. Since that time, there have been major changes and advances in how building and construction projects are managed and delivered and there has been significant change in the commercial landscape in the design, construction and materials supply sectors. The process of how research findings have been implemented into practice has been complex over this time and it has changed with changing commercial and academic environments. How commercial and government segments communicate research needs to academia has also been interesting to observe over time.

This paper considers the role of academic research and its communication and application into engineering practice mainly from a materials supply perspective. This sector forms a major part of the construction industry and underpins infrastructure and building development. It employs a major number of specialist engineers and applied scientists and has had a major link to research over the last 30 years. Importantly, this sector of industry has strong links with the engineering design sector and covers materials such as concrete, binders, aggregates, structural fills, roadbase materials, chemical and mineral admixtures and a vast range of products for construction.

KEYWORDS

Concrete, durability, history, engineering, sustainability, industry, research, commercial.

INTRODUCTION

In the last 30 years, there have been major changes and advances in how building and construction projects are managed and delivered and there has been significant change in the commercial landscape in the design, construction and materials supply sectors. The main change has been the contraction of the technical sector within government and the emergence of contractor based delivery of infrastructure (including design responsibility). In Australia, about 23 million cubic metres of concrete are produced per year (ABS, 2009). This includes pre-mixed concrete as well as precast concrete components, although it is most widely used in pre-mixed form (NRMCA, 1982). Precast concrete, as the name implies, is that material that is manufactured in a factory and transported to a construction site in a fully cast (hardened) form, typically as a slab, beam, column, unit or other concrete element. Virtually no construction is possible without the use of concrete in one or other forms. The fundamental components of concrete are:-

- Portland cement, (defined in AS3972),
- Supplementary cementitious materials (defined in AS3582.1)
- Aggregates that are either coarse and/or fine (defined in AS2758.1)

- Water that is either potable or recycled (defined in AS1379), and
- Chemical admixtures (defined in AS1478.1).

These fundamental components are being broadened to include new systems such as alkali activated materials, the most common being geopolymer concretes. In mentioning geopolymer concretes, there is a significant research effort going into developing such technologies and there are many different types of material being developed and investigated which suggests that the broad classification of such products under one heading may change in future. Importantly, it is thought that there are opportunities to better link the research effort into current standard and specification frameworks. There are a range of other components that go into concrete that include fibres both steel based and synthetic based. There has been significant and major developments in technology related to such products in the last 30 years. In many cases, such research has been done commercially by organisations and has not linked with traditional academic effort.

WHY CONCRETE?

Concrete is one of the most widely used construction materials on the planet. Concrete starts its life as a batched material, produced by mixing component materials in an agitator to produce a plastic material. In this state, it can be:-

- Transported to a construction site,
- Discharged into a concrete pump to facilitate transfer at the construction site into a concrete form (a designed temporary structure within which plastic concrete is placed to form a final concrete structural element such as a slab, beam or column and covered by Australian Standard AS3610 (Standards Australia, AS3610, 2010),
- Placed into a concrete form and spread within that form in its plastic state to fill the form void (following which evaporation retardants are applied to reduce early age evaporation),
- Compacted by internal vibration to remove air voids,
- Finished at the surface of the form, or the structural element, to provide a surface that is flat and functional for its designed purpose, and then
- Cured for ensuring that the hydration of Portland and blended cements in freshly placed concrete continues for sufficient time to develop its design strength, durability and other performance characteristics.

After about 24 hours following placement, concrete commences its hardened state whereby it gains compressive strength. The compressive strength of concrete is the most commonly specified parameter measured at 28 days, although compressive strength measurements can also be measured at other times. Traditional concrete will continue to harden after this period at a reduced rate and will gain strength years after placement.

Concrete is a cost effective construction material that is used on most projects for the construction of buildings or infrastructure. The concrete supply sector (that covers aggregate and cement supply) employs a vast number of civil engineers and other scientific based practitioners in Australia and in other parts of the world. There is major investment in quarry infrastructure and cement kilns in Australia and overseas. This coupled with concrete production facilities and transport infrastructure results in significant need for engineers and engineering services.

CONCRETE MATERIALS SUPPLY IN A HISTORICAL CONTEXT

The origins of concrete are not clearly known. It is a material that gradually evolved over centuries rather than one which commenced life at a particular time in the form that we currently understand. No one really knows who made the first concrete but it has had a huge impact on civilisation over the centuries. Huts for fishermen on the banks of the River Danube in old Yugoslavia have been dated back to 5600BC. These are thought to be the earliest forms of concrete in the sense that the materials are bound together using red lime, sand, gravel and water. The Great Pyramid at Giza in ancient Egypt was built around 2500BC, thought to be constructed using a form of concrete (Neville, 1977).

The skills developed were lost for about 600 years and construction reverted to manufacture using mud until concrete was re-discovered and developed by the Egyptians. The Egyptians, followed by the Romans and the Greeks, used various forms on natural cements, developed this technology into the dominant construction material over a period of around 800 years (Lewis, 1988). The earliest work of an ancient "Concrete Producer" is recorded on a mural from Thebes in Egypt dating from 1500BC. The Romans used these natural cements to build sewers, water pipes, baths, piers, breakwaters, aqueducts and other structures. Many of these used concrete to infill between layers of masonry or stone, thus adding both strength and weight to the structure. Arches, vaults and domes were features of these developments as is evidenced by the aqueducts and structures like the Colloseum (AD80) and the Pantheon (AD150) which features a large lightweight concrete dome (Lewis, 1988).

These early materials were mixtures of lime, sand, gravel and water, but it is also known that the Egyptians made natural cements that would set and harden under water. Some of these relied on the cementing action that came from the naturally occurring pozzolans used in association with lime. The most common of these pozzolans was from Mt Vesuvius. Table 1 summarises notable events in the history of concrete developments taken from a range of references, mainly to describe the broad and long history of the development of this complex material.

Neville (1977) notes the first recorded use of concrete to be in Roman times where calcined limestone was added to lime, water, sand, crushed stone, broken tiles and brick to produce a composite material. Following pioneering work in the mid 1700's by many workers, a patent for "Portland cement" was taken out by Joseph Aspin in 1824 (Neville, 1977). In Australia, it has been reported that the manufacture of Portland cement began in the late 1800's in Victoria with the first use of reinforced concrete again in Victoria recorded in 1911 (Nagarajan and Antill, 1978, Lewis, 1988).

As noted previously, concrete is most commonly used in pre-mixed form (NRMCA, 1982). The idea is to mix the component materials at a dedicated location and then transport concrete in the fresh state to the construction site. This has significant advantages as concrete typically has a mass of about 2.4 tonnes per cubic metre. For this, concrete mixing machines are required. These can be in a building (like a concrete batch plant) or mounted on a vehicle (termed a concrete agitator).

The history of concrete mixing machines stretches back over 150 years and is broadly summarised in Table 2. It evolved slowly with the first machines being horse driven and progressed to steam driven mixers before hydraulic equipment was developed. From the early 1900's the developments leading to the current concrete mixer began with the use of tilting drum mixers (NRMCA, 1982). Importantly, concrete mixing is the process of getting component materials mixed into a homogenous mass. Agitation is the process of keeping mixed concrete from segregating whilst transporting in the fresh state (i.e. ensuring that the coarse and fine aggregates do not stratify in the mass and that all components remain homogenously distributed).

Australia has had some notable events/successes with pre-mixed concrete. Australia was the first in the world to handle low slump concrete. It was the first to widen the mouth of the drum for fast charging and discharging of concrete from agitators. It lead the world in mix uniformly and the introduction of mixer efficiency testing (NRMCA, 1982, Lewis, 1988).

A broad history of concrete in Australia is summarised in Table 3. In this Table, the following is noted:-

- Applications of concrete in structures
- Significant (early) uses of Portland cement in construction
- Formation of the various industry associations and learned societies related to cement, concrete and reinforcement

- Significant (early) use of concrete of different types (reinforced, prestressed etc.), and
- Development and initial publication of Australian standards for concrete design.

Table 1. Notable Events in the History of Concrete Development
(NRMCA, 1982, Neville, 1977, Nagarajan and Antill, 1978, Lewis, 1988)

Year	**Event**
Early 1700's	The first recorded use of concrete (as a mixture of stone like materials, a binder and water)
1756	Engineer John Smeaton commissioned builds a lighthouse off the Cornwall coast in England this by using a mixture of burnt limestone and Italian pozzolan that lasted 123 years
1824	Patent on "Portland Cement" taken out by Joseph Aspin
1830	First recorded reference to reinforced concrete referring to iron bars used in a concrete roof
1848	Lambot (French citizen) built concrete rowing boats as the fore runner to ferrocement construction, later perfected by L Nervi
1854	The first reinforced concrete was patented. This was in England involving a reinforced concrete flooring system
1867	Jean Monier patented the process for making reinforced concrete pots for trees and flowers
1879	Monier obtained patents on the building of reinforced concrete pipes, reservoirs, floors and bridges
1885	The first concrete mixer was developed. This was a paddle type mixer
1886	The first USA patent for prestressed concrete was granted. This was not successful due to the low quality of the stressing wire used
1891	The construction of concrete pavements and roads commenced
1900	Concrete drum mixers started to replace the older paddle type mixers
1907	Steel reinforcement was introduced in the form of the Kahn bar
1909	The development of the concrete transit mixer commenced, using horse drawn equipment
1910	Reinforcing mesh was patented and introduced
1912	While it is known that pumping occurred before patents were taken out the earliest record of pumping concrete is the first patent to W G Wilson in USA for a "machine for mixing and depositing concrete and other materials."
1913	Kooyman's concrete pump was invented in Germany
1928	Eugene Freyssinet of France developed the technique of using high strength prestressing wires and started the prestressed concrete industry
1963	Steel fibre concrete (in its broad current form) was used The Squeezecrete pump developed by Challenge- Cook was introduced

CONCRETE STANDARDS

Design and Supply

The main Australian Standards covering design, specification and supply of concrete are AS3600, Concrete Structures (Standards Australia, AS3600, 2009) and AS1379, Specification and Supply of Concrete (Standards Australia, AS1379, 2007). AS3600 has been issued in many forms since it was first published in 1934 as CA2 (Standards Association of Australia, Australian Standard CA2, 1937). This followed revisions of CA2 in 1958, 1963 and 1973. The standard then changed to become AS1480 in 1974 (SAA Concrete Structures code) and was updated and published in 1982. It was then changed to the current AS3600 and first published in 1988 followed by revisions in 1994, then in 2001 and then in its current form in 2009.

Table 2. Notable Events in the History of Pre-Mixed Concrete
(NRMCA, 1982, Neville, 1977, Nagarajan and Antill, 1978, Lewis, 1988)

Year	**Event**
1902	Mechanical mixers started to overtake hand mixing to facilitate ease of construction
1904	Magens gained the first UK patent on ready mixed (pre-mixed) concrete
1908	Concrete pan mixers were developed in UK (a stationery concrete mixer)
1910	Self discharging mixers began to be developed
1913	A patent for an “apparatus for mixing and distributing concrete” was granted
	The majority of the initial pre-mixed concrete technology came to Australia from USA and relied on the work being done on large dams. Mixing was done using large horizontal drum or tilting mixers. The resulting concrete often suffered due to the poor transport methods used which led to segregation problems (where component materials were not being mixed properly resulting in defective concrete).
1920	The Rex drum mixer was developed. This was one of the first mixers to be mounted on a truck. This was the start of what would eventually become known as the transit (concrete) mixer or agitator
1926	The first concrete transit mixer was used in USA
1930	Tumblebug agitators (a further development) were introduced to agitate and transport concrete
1939	The first Australian plant using a fleet of tumblebug agitators was opened at Glebe Island in Sydney, operated by Ready Mixed Concrete Limited *This was a 3 cubic yard stationary central mixer and a fleet of 5 horizontal drum agitators known as Tumblebugs mounted on 1939 White trucks. These were not mixing machines but could agitate and overcome the segregation problems previously associated with transporting concrete. The drum was a horizontal cylinder which revolved to agitate the concrete. It was charged through a hatch in the side of the drum and was discharged by tilting the drum about its rear support and opening the guillotine door at the rear, allowing the concrete to flow out under gravity.*
1944	Certified Concrete commenced a pre-mixed concrete business at Annandale in Sydney using 2½ cubic yard inclined axis transit mixers which enabled materials to be transported dry over long hauls and water added on site.
1948	Ready Mixed Concrete Limited and Certified Concrete both imported Rex Mixers which were the first inclined drum mixers built in the world. These provided mixing action and were a major advancement in mixer technology.
1952	Nearly all of the machines used in Australia until 1952 were 3 to 4 cubic yard capacity. In that year Moorfield Engineering made 6 cubic yard machines under license to Challenge Cook of USA. These proved to be more efficient and could discharge concrete with slumps (a measure of flow or workability of concrete – described later in this report) as low as 2 inches.(50mm)

The Australian Standard covering specification and rules for storage of binders, aggregates and other components at a concrete batch plant are defined in AS1379 (Standards Australia, AS1379, 2007). Most concrete batch plants in Australia are dry batch plants where components are weighed and transported into a concrete agitator (the requirements for which are defined under AS1379). This standard is very important as it is the document that references component material standards and testing standards required for supply to projects. This standard originated as AS (E)A502, Ready Mixed Concrete in 1941 and revised and redesignated as AS1379 in 1991 followed by revisions in 1997 and 2007.

Table 3. History of Concrete in Australia
(NRMCA, 1982, Nagarajan and Antill, 1978, Lewis, 1988))

Year	Event
1870	Verandahs of Parliament House – Brisbane constructed
1871	Footings of Maryborough Court House
1878	Base of South Brisbane Dry Dock
1882	Portland Cement first made in South Australia
1896	Lamington Bridge at Maryborough constructed
1896	Sewage Aqueduct at Forest Lodge in NSW completed
1900	Substructure for Queensland Rail Bridges on the Toowoomba line
1904	Bradleys Head Lighthouse in Sydney harbour constructed
1907	Retaining wall systems in Sydney Harbour developed by Monier
1910	Circular Quay floating berths no 6 & 7 cast
1914	Brisbane's first concrete road in Isles Lane constructed
1919	Cement Manufacturers Association (now CCAA) formed
1917	Portland cement first made by Queensland Cement Limited at Darra
1920	Welded Wire Fabric made in Australia
1922	Queen, Roma & George Streets in Brisbane constructed using concrete
1925	First version of the Australian Standard for cement published
1934	The Concrete Structures Code first published in Australia as CA2
1946	The formation of the Cement and Concrete Association of Australia (C&CAA)
1948	North Australian Cement Plant constructed in Townsville (Closed in 1995)
1950	Precast concrete used in bridge building in Australia
1955	Early use of prestressed concrete in bridges in Queensland (built for the railways)
1962	Formation of the Australian Prestressed Concrete Group (now the Concrete Institute of Australia)
1966	Central Queensland Cement Plant constructed at Rockhampton
1967	Formation of the National Ready Mixed Concrete Association (NRMCA)
1969	Formation of the Concrete Institute of Australia
1974	AS1480, the Australian Standard Concrete Structures Code published
1975	First modern concrete highway at Clybucca Flat near Kempsey Formation of the Steel Reinforcement Group (now the Steel Reinforcement Institute of Australia)
1976	QCL construct the Bulwar Island Grinding Plant
1982	QCL construct the Gladstone Clinker Plant
1985	Sunstate construct a cement grinding plant in Queensland
1988	Steel Reinforcement Institute of Australia (SRIA) formed and AS3600 Concrete Structures first published
1994	Formation of the Australian Pre-Mixed Concrete Association (APMCA)
2003	Formation of Cement, Concrete and Aggregates Australia following amalgamation of C&CAA, APMCA and Extractive Industry Associations

Component Material Standards

There are a range of cements and binders described in the literature specific to Australia (Guirguis, 1998, ADAA, 2009, Concrete Institute of Australia, 2003a, Concrete Institute of Australia, 2003b, ASA, 1997, Concrete Institute of Australia, 2006). The term "cement" is defined in Australian Standards AS3600 and AS1379 as a hydraulic binder composed of Portland or blended cement used alone or combined with one or more supplementary cementitious materials. This broad definition encompasses fly ash, slag and/or amorphous silica within the definition of cement. The term "binder" is used in this paper to recognise the differences between Portland cement, supplementary cementitious materials and blends of Portland cement and supplementary cementitious materials.

Portland cement is defined in AS3972 (Standards Australia, AS3972, 2010) as a hydraulic cement that is manufactured as a homogeneous product by grinding together Portland cement clinker and calcium sulfate. Portland cement clinker is defined as is the partially fused product resulting from the intimate mixing of calcareous and argillaceous or other silica, alumina, or iron-bearing materials, or any combination of these materials, and burning them at a clinkering temperature.

Portland cement clinker specified to contain less than 4.5% MgO. Importantly, there has been a standard for Portland cement in Australia since 1925 (AS A2). The standard was revised and redesignated as AS1315 (Portland Cement) in 1973 and then revised in 1982. The standard was revised and redesignated as AS3972 in 1997 with a revision published in 2010.

A supplementary cementitious material (SCM) is that used in concrete in conjunction with Portland cement that then forms part of the (cementitious) binder portion. SCM's are defined in Australian Standard AS3582 as fly ash, slag or amorphous silica. A blended cement is hydraulic cement that contains general purpose cement and which, at the discretion of the cement manufacturer, may contain one or both of greater than 7.5% of fly ash or ground granulated iron blast-furnace slag, or both, or up to and including 10% amorphous silica. The Australian standard for fly ash is AS3582.1 (Standards Australia, AS3582.1, 1998) and this originated as AS1129 and AS1130 in 1971. It was revised and redesignated as AS3972.1 in 1991 with a second edition published in 1998. The Australian Standard for ground granulated iron blast furnace slag (slag) is AS3582.2 (Standards Australia, AS3582.2, 2001). This originated in 1991. The Australian Standard for amorphous silica is AS3582.3 (Standards Australia, AS/NZS3582.3, 2002) and this originated in 1994 and was jointly revised and designated as an Australian and New Zealand standard in 2002.

By volume, coarse and fine aggregates occupy more space than any other component in concrete; therefore, careful consideration of aggregate properties is essential for the development of quality concrete. The Australian Standard for concrete aggregates is AS2758.1 (Standards Australia, AS2758.1, 1998). A range of concrete aggregates are defined in this standard. The aggregate standard originated as AS A24 in 1934. The first edition of AS2758.1 was published in 1985 with a revision published in 1998.

Chemical admixtures are defined in AS1478.1 (Standards Australia, AS1478.1, 2000) as materials other than water, aggregates, and cementitious materials, used as an ingredient in concrete, and added to the batch in controlled amounts immediately before or during its mixing to produce some desired modification to the properties of the concrete. Almost all concrete supplied incorporate chemical admixtures and these have developed significantly in the last 20 years. The standard for chemical admixtures in Australia originated in part of AS A173 and AS CA58 in 1969 and was redesignated as AS1478 in 1992. The standard was revised and published in 2000.

ROLE OF ACADEMIC RESEARCH

Standards for concrete and component materials for concrete have been around in Australia since 1925. The design standard for concrete dates back to 1934 in Australia. This generally reflects the presence and activity of industry sectors involved in the production and supply of concrete and component materials, and groups who use these materials in construction in Australia. Australia has a long and rich history of the production, supply and use of concrete in construction and academics have played a part in its development.

More recently, with increased commercialisation, there has been a focus away from technical aspects of the material to a more project and commercial focus on supply. This may have resulted in the possible increase in distance in research into the material and related issues, and the commercial supply and use of the material in its broadest form. To bridge this gap, it is important for academics to become a bit more commercially aware of the workings of the supply industry including those who design material, construct with it and those who manage infrastructure made with it. It is conversely important for practitioners in the various industry sectors to become more aware of academia and how it functions in Australia particularly as it relates to their industry sector.

There are a significant number of industry groups involved in concrete and other heavy construction materials and the scope and diversity of these industry sectors is too broad to cover in this paper. Importantly, when industry sectors develop, so too does the formation of industry associations (providing education and advocacy) and the formation of professional and learned societies (to develop and deliver knowledge). Industry associations and learned technical societies provide a key link for external groups into an industry sector, providing information on key issues of interest to their respective groups. In Australia, industry sectors involved with concrete are mature having had long histories of operation. Below is a brief synopsis of some key groups in the concrete design and materials and supply sectors.

Design

- 1919 – Formation of the Institution of Engineers Australia (now Engineers Australia)
- 1952 – Formation of the Association of Consulting Engineers Australia
- 2010 - ACEA renamed to Consult Australia

Materials and Supply

- 1919 Formation of the Cement Manufacturers Association (now CCAA)
- 1962 Formation of the Australian Prestressed Concrete Group (now the Concrete Institute of Australia)
- 1967 Formation of the National Ready Mixed Concrete Association of Australia (NRMCA – now CCAA)
- 1969 Formation of the Concrete Institute of Australia (renamed from the Australian Prestressed Concrete Group)
- 1969 Formation of the Concrete Pipe Association of Australia
- 1975 Formation of the Steel Reinforcement Group (Now the Steel Reinforcement Institute of Australia)
- 1988 Formation of the Steel Reinforcement Institute of Australia (SRIA)
- 1990 Formation of the Australasian (Iron and Steel) Slag Association
- 1990 Formation of the National Precast Concrete Association of Australia
- 1991 Formation of the Ash Development Association of Australia – ADAA (prior to that was the National Ash Association composed of marketers only – ADAA covers producers and users)
- 1994 Formation of the Australian Pre-Mixed Concrete Association (APMCA)
- 2003 Formation of Cement, Concrete and Aggregates Australia (following amalgamation of C&CAA, APMCA and Extractive Industry Associations)

There are some recurring themes that come about when concrete is discussed. These include:

- Shrinkage and its management
- Cracking and its management
- Durability and what it means in all its facets
- Sustainability and working out what it means and how it might apply in infrastructure, construction, design and supply
- Performance criteria for plastic, hardening and hardened states
- Product manufacturing optimisation and design
- Cost and risk reductions

A WAY FORWARD

The pursuit of commercial and operational agendas for industry groups and increasing demand on academics to meet teaching and other requirements are generally thought to be having the influence of pushing key practitioners within these groups apart. Some view the long term benefits of enabling increased contact between industry sectors and academics as critical to long term benefit for all. There are many schemes designed to award and benefit industry to do more research as there are schemes for academics to be more involved with industry. Whilst the intensions are good, such schemes have much room for improvement.

No scheme or incentive will replace the desire for individuals within the two groups to interact better. This is where the power of industry associations and learned technical societies come into play. Academics having the desire to spend some of the research effort on networking will find benefit. Also and importantly, industry practitioners may find that some of their marketing budgets could be most usefully spent networking with academics, finding out what they do, learning about their capabilities and communicating to them their problems and issues that can possibly translate into fundamental and tactical research.

There are a number of key issues facing commercial industry sectors and academia at present impacting on research support. The need for research is currently thought critical; however, processes to support it remain a challenge. From a time where government funding underpinned research both in authorities and in academia, models for project delivery have changed and become more commercial. This has seen a loss of direct focus on research in the broad construction industry and engineering practice. This has resulted in academics pursuing other areas of research interest where there is more support. There is also a current shortage of high level technical people in the construction industry, something that needs to be addressed within the next 10 years. Only by continuing research can commercial enterprises achieve cost reductions, risk reductions and improved sustainability, themes that reoccur in many sectors. This has the added benefit of producing new people who will become technical leaders in commercial and government spheres required for the future. The role of academia in this process is critical and will require solid and detailed communications with commercial and government entities to ensure that the right topics are addressed in the pursuit to remain competitive on a global scale.

It has been shown that the use of concrete in all its forms has a long history and not everything we do in research is necessarily new. There have been industry associations and learned societies in operation in Australia since 1919. There have been standards in Australia on cement since 1924. There has been a concrete structures code in Australia in operation since 1934. There have been standards on fly ash in Australia since 1973 and slag since 1991. Academics need to take advantage of this long history and see it as an opportunity to differentiate their research and increase their chances of implementing their important work into practice with increasing efficiency. Industry sector practitioners would play a key role in this in seeking out academics and supporting them through the process to better reflect their needs.

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