ENGINEERED CEMENT POLES - DURABILITY REVIEW

A review of relevant literature demonstrating the properties of polymer modified cement products including those reinforced with glass fibre. The review was commissioned by Dulhunty Poles Pty Ltd to assist in the understanding of the life expectancy of Engineered Cement Poles (ECP) made using a combination of Portland Cement, Kaolin, acrylic latex polymer and alkaline resistant glass fibre.

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Executive summary

This review, commissioned by Dulhunty Poles Pty Ltd Managing Director Mr Tony Wingrove, aims to provide reliable well researched customer advice on the durability and lifetime performance of the company's recently launched Titan range of engineered cement poles (ECPs) for use in low to medium voltage power distribution and sub transmission lines.

Titan ECP's using polymer modified cement have only been made since 1999. There is however substantial evidence of the performance of polymer modified cement in other types of concrete construction, mainly buildings, from at least the 1960s. The two key performance attributes to be demonstrated relevant to ECPs are that:

- modification with acrylic polymers makes cement based products more durable (i.e. having longer useful lives in a range of service conditions including climate, wind, rain, temperature range, sunlight, etc).
  - The literature shows it achieves this by increasing strength, abrasion resistance, UV stability, crack resistance, chemical resistance, density and impermeability.
- modification with acrylic polymers makes alkaline resistant glass reinforced cement materials more durable.
  - The literature shows it does this by increasing the cement/reinforcement bond and by preventing reinforcement corrosion from pH variation over long periods

To this end, a number of papers and industry articles, relevant to the ageing, durability and sustained strength of ECPs and their formulation, have been carefully reviewed (see References below). In summary these papers, in the main prepared by international researchers, research organisations and suppliers over a lengthy period, show that acrylic polymer modification can be expected to provide enhanced durability and ageing properties as compared to unmodified cement products.

As well as providing enhanced durability and ageing properties, the literature review and the many test programs cited show that acrylic polymer modification adds significantly to strength and flexibility of the cement and its compatibility for forming a strong, intimate and lasting bond with alkaline glass reinforcement.

Titan ECP manufacture

It is first useful to outline briefly the processes used in the formulation, manufacture and curing of Titan engineered cement poles (ECPs).

Cement slurry

The cement slurry used for ECP manufacture is a high strength polymer modified cement mix of dry and wet raw materials. The dry materials are Portland cement and an ultrafine pozzolanic clay filler.

The wet materials are water, latex emulsion and a high range water reducer. The latex emulsion is a pure acrylic copolymer with processing additives suspended in water to give the added strength, flexibility and durability needed in ECPs to ensure that the material will endure for its expected 70 year life or more, even under adverse climatic and operational conditions.

Reinforcement

ECP's are reinforced with fine 100% alkali resistant glass filaments, as distinct from less costly 'E glass' which has only alkali resistant coating. The acrylic modifier in the slurry, which inhibits pH variation through the material, further assists in cement glass bonding and eliminating corrosion of the reinforcement.

Manufacture and curing

ECPs are formed on a vertical rotationally oscillating mandrel. The slurry mix is added uniformly from a bath as the glass fibre filaments are applied in accordance with a preset design program, until the desired wall thickness and reinforcement lay for the specified pole performance is reached. Upon completion the pole is wrapped in a protective plastic coating for 24 hours, until the rapid first cure is complete, following which the mandrel and the protective coating are removed.

Literature review and findings

This section reviews the various materials used in or available for engineered cement product manufacture and the physical properties each can confer to the cement matrix. This is provided to underscore the rationale for material selections and methods employed in the manufacture of Titan ECPs.

The findings are drawn from and supported by the extensive literature reviewed, as set out below under References.

Portland cement

Cement is characterized as hydraulic or non-hydraulic. Hydraulic cements (e.g. Portland) harden due to hydration, a chemical reaction that occurs independently of the mixture's water content. Such cements can even harden underwater or when constantly exposed to wet weather. The chemical reaction when anhydrous cement powder is mixed with water produces non water-soluble hydrates. Cement is used for producing mortar and concrete, bonding natural or artificial aggregates (gravel and/or sand) to form a strong and durable construction material. Correctly prepared but without modification, Portland cement produces high compressive strength concrete. However unmodified cement products, while well suited for example to mass concrete foundations, have two attributes that restrict their use in thin layers: brittleness and poor adhesion.

Polymeric modifiers

Polymeric modifiers have been used since the 1960s to increase the durability, flexural strength and service life of Portland cement concrete, so increasing its potential uses. Such modifiers also improve adhesion of the cement to the substrate (eg reinforcement).

Several types of polymeric materials are used to improve flexibility and overall strength of concrete products beyond that of unmodified concrete; careful design attention being needed to match the modifier to the proposed use. A variety of cement formulations is possible with acrylic lattices depending on the desired design properties; hence the descriptor 'engineered cement pole' or ECP. Some modifiers, for example, can discolour the cement with ageing; some have poor freeze-thaw performance and some poor water resistance. Hence the modifier used has to be considered, bearing in mind the end application.

The three generic modifier families are:

- Acrylic latex polymers (as used in Titan ECPs);
- Styrene-butadiene resin (SBR) polymers; and
- Ethylene vinyl acetate (EVA) polymers.

Each of these, together with the finished cement properties endowed through its use, is described below.

Acrylic latex polymer modifiers

Acrylic refers to a large family of resins derived from the polymerisation of derivatives of acrylic acid. Acrylics have similar chemical structures but a wide range of properties and are used to modify Portland cement products. Not all acrylics are suitable for use with cement; specific acrylic latex formulations compatible with Portland cement are needed to achieve the performance properties required of the end product. These are generally commercial proprietary products, typically water based acrylic polymers (lattices), polyacrylates and polymethacrylates. Methacrylate polymers provide for harder concrete, higher tensile strength and lower elongation, while butyl polymers provide for greater flexibility.

Commercially available acrylic based modifiers are specifically designed to overcome the shortcomings of unmodified concrete, especially cracking, poor adhesion and breakaway from substrates (eg reinforcement) under continued flexure, low impact strength, erosion, temperature cycling and load reversals. Acrylic polymers do not absorb UV radiation and are not vulnerable to hydrolysis in the high pH environment of Portland cement. The modified concrete is effectively water resistant, hence offering excellent outdoor durability. The material is well suited to ECPs but careful selection, proportioning, measuring and mixing is essential.

Even after nearly 40 years outdoor testing, acrylic latex polymer modified concrete exhibits the following improved design properties, relative to unmodified concrete:

- Thin section toughness;
- Adhesion to substrates (i.e. shear bond adhesion, including to reinforcement);
- Enhanced mechanical strength and flexibility (i.e. tensile and compressive strength);
- Enhanced impact and abrasion resistance sustained over time;
- Chemical and corrosion resistance (i.e. minimal weathering evidence);
- Corrosion resistance;
- Liquid water resistance; and
- UV stability.

The literature reviewed expands on a number of these enhanced design properties and their underlying science.

Thin section toughness: Controlled curing and hardening of acrylic polymer modified cement bestows for significantly enhanced properties, as compared to unmodified cements. While unmodified cement curing generally needs continuous and controlled moistening over an extended period, typically 28 days, acrylic modified cement self retains hydration water for the full curing period, allowing air curing under ambient conditions. This rapid first cure is crucially important for thin prefabricated products, such as factory produced building panels and ECPs, where mould turnaround times must be minimised. Moreover eliminating moist curing while providing thin section toughness can bring significant labour and material cost savings.

The mechanism by which acrylic modifiers assist in retaining cement moisture during air curing is of interest. It is believed that the polymer coalesces to form a water holding film around the Portland cement grains during the hydration reaction, so speeding pole curing and preventing evaporation during curing, even in very thin applications. Additionally polymer modified concrete exhibits equal workability at significantly lower water levels than unmodified concrete, known as the superplasticiser effect.

Thus, to obtain the maximum desired physical properties for an engineered product, acrylic latex modified cements are air cured at ambient room temperature and humidity with care taken to avoid unduly rapid initial dehydration. For unmodified cements, for example for mass concrete foundations and beams, the opposite is true; optimum strength properties are achieved by traditional wet curing.

Adherence to substrates: Acrylic polymers assist the cement in adhering tenaciously to wood, metal and other substrates including glass filament reinforcement. The latex emulsion reduces the liquid surface tension, ensuring improved wetting of the cement and metakaolin and hence more intimate penetration of, and adherence to, the reinforcing filaments. Laboratory shear testing shows that substrate failure with polymer modified cement consistently occurs before bond failure, testament to the enhanced bond shear strength bestowed.

Enhanced mechanical strength and flexibility: The polymer film provides improved flexibility to the cement matrix and hence resistance to cracking and impact. The polymer film absorbs energy from micro crack propagation, thus terminating micro cracking at the outset, enhancing mortar toughness (i.e. tensile strength) and improving strength and hardness to give greater abrasion and weathering resistance. A significant property of acrylic latex modified cement is thus increased flexibility (i.e. strain capacity).

Enhanced impact and abrasion resistance sustained over time: Acrylic polymer modified cements, under extended weathering tests, show significant and sustained improvements in impact strength, modulus of rupture (MOR), flexural yield and abrasion resistance. These properties have been demonstrated to be sustained over extended lifetimes.

Chemical and corrosion resistance: Acrylic latex modified cements show strong resistance to chloride ions, enhancing their suitability for salt laden marine and coastal environments and, in the future, their potential application for lightweight long lasting marine piles.

Liquid water resistance: Acrylic polymer modified cements exhibit the outstanding water resistance, tensile strength and reinforcement adhesion necessary to resist extended freeze-thaw wet-dry cycling, and hence the surface durability to withstand weathering, UV degradation and discolouration. This long term matrix stability and hence durability, demonstrated under extended testing, is achieved through internal sealing of the slurry by the emulsion, so preventing lime migration and pH change over the product life. The whole of life exterior durability of acrylic polymer modified cements is thus outstanding; a property that is critical to formulated (i.e. engineered) products.

UV stability: Acrylics are inherently durable under most outdoor conditions because they are largely transparent to natural sunlight. They do not absorb UV radiation or discolour, unlike some other modifiers. Atmospheric exposure testing by Rohm and Haas and others in the USA over nearly 40 years has well demonstrated (and quantified) the significant performance and long term durability enhancements attributable to acrylic latex modifiers, as compared to styrene-butadiene rubber (SBR) which shows only a slight improvement over unmodified cements.

In summary, film-forming acrylic latex emulsion Portland cement modifiers provide a number of design benefits relevant to ECPs, most importantly high long term durability as well as improved hydration, greater strength and increased flexibility.

Styrene-butadiene rubber (SBR) polymers

(SBR) is a synthetic rubber copolymer consisting of styrene and butadiene. It has good physical properties and excellent abrasion resistance but is sensitive to oil, wastewater and ozone. It has good ageing stability when protected by additives and is widely used in car tires blended with natural rubber.

SBR is a commodity material which competes with natural rubber over a range of uses. In buildings it is used as a sealing and binding agent behind renders as an alternative to PVA, offering better durability, reduced shrinkage and increased flexibility, as well as resistance to emulsification in damp conditions. It is used for example to 'tank' damp rooms.

SBR polymers can be added as a modifier to cement mixes. However SBR absorbs UV photons which, in time, can break the polymer bonds. Although highly hydrophobic, SBR modified mortar erodes under outdoor exposure leading to long term degrading. It is accordingly unsuited for long life expectancy products.

Ethylene vinyl acetate (EVA) polymers

EVA is a copolymer of ethylene and vinyl acetate which approaches elastomeric materials in softness and flexibility, yet can be processed like other thermoplastics. The material has good clarity and gloss, good barrier properties, low-temperature toughness, stress-crack resistance, hot-melt adhesive water proofing properties and is resistant to UV radiation.

EVA polymers can be added to cement mixes as a dry powder. However EVA modified mortar is water sensitive and substrate adhesion decreases under water exposure. This makes EVA unsuitable for products for wet environments. Test results, as relevant to the properties required for ECPs, confirm its unsuitability.

Glass fibre filament reinforcement

Glass fibre reinforced concrete (GRC), a composite of a cement and very fine aggregate mix with fine glass fibres, has been used for around 40 years for a variety of high duty concrete applications. The glass filaments are 100% alkali resistant to maintain long term performance. Significant durability research has been carried out on GRC performance; the knowledge base is sound.

GRC is thus a cement-rich low permeability composite product with high chemical resistance and a low rate of carbonation, giving a high degree of durability without the corrosion concerns that can arise with steel reinforcement. GRC properties are highly predictable, well understood and well documented. Product design typically adopts a conservative approach, with design loads within the elastic limits of the material and below the stress levels at which cracks would begin to appear in the GRC matrix. However in severe over design loading conditions the ductility of the glass reinforcement provides for a significant margin of added flexibility and operational safety.

The use of an acrylic polymer modifier impedes moisture movement and assists curing; moreover it improves ductility through its presence at the fibre/matrix interface. Highly active pozzolanic additives (eg metakaolin - see below) react with calcium hydroxide as it is produced, resulting in lower alkalinity in the matrix and less crystallisation around the fibres, so avoiding reinforcement degradation over time and hence retained ductility.

It is claimed that good quality GRC ductile lifetimes of 60-80 years can confidently be expected in severe weathering conditions.

Metakaolin filler

Metakaolin, as used in ECPs, is a dehydroxylated form of the clay mineral kaolinite, sometimes known as china clay or kaolin and used in porcelain manufacture. It is used for high performance, high strength and lightweight structural concretes.

Dehydroxylisation is a kiln process carried out between 500°C and 800°C in which kaolin is transformed to metakaolin. This material has strong pozzolanic (cementing) properties when added to cement, the particle size being much smaller than cement particles. Where metakaolin is used as a filler in high strength concrete applications it is considered to have twice the reactivity of most other pozzolans. Mixed with Portland cement it produces a concrete mix with superior engineering properties which, as relevant to ECPs, are:

- Increased compressive and flexural strength;
- Reduced permeability (including chloride permeability);
- Reduced efflorescence, which occurs when calcium is transported by water to the surface where it combines with atmospheric carbon dioxide to form calcium carbonate which precipitates on the surface as a white residue;
- Reduced effects of alkali-silica reactivity (ASR);
- Enhanced workability and finishing of concrete;
- Reduced shrinkage due to particle packing making the concrete denser;
- Increased resistance to acid and chemical attack; and
- Increased durability and weathering capability.

Each of these properties is consistent with and supportive of the enhanced cement properties endowed by acrylic latex polymer modifiers. Thus it can safely be concluded that appropriate modification with properly selected acrylic latex polymers will make engineered cement products more durable (ie having significantly longer useful lives in a range of service conditions including inclement climates, wind, rain, temperature range, sunlight, etc) as compared to unmodified cements.

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The Author

Martin Thomas AM FTSE HonFIEAust FAIE is chairman of Dulhunty Poles Pty Ltd. He has prepared this paper following a comprehensive review of relevant literature, from searching questioning of company executives and from his understanding of the Titan pole formulation and manufacturing processes from materials selection through to sale product.

Martin Thomas graduated from Cambridge University UK in 1957. He came to Australia in 1967, following a career in the power and energy sector with Merz Australia. Following a merger he became a Principal of Sinclair Knight Merz. During his consulting career he was responsible for power projects in Australia, the Pacific Islands, South East Asia, Africa and India. In the 1980's he established the industry export association Austenergy.

From 1988 to 1994 he was independent Chairman of the New South Wales Electricity Council, charged with advising the NSW Minister for Energy on matters of industry corporatisation, deregulation and competition. This role included chairing a Ministerial Inquiry into power distribution in the far west of NSW, as well as reporting upon industry issues associated with the State's HV and MV transmission and distribution systems.

He was President of the Institution of Engineers Australia from 1991-92 and elected an Honorary Fellow in 1996. He served as President of the Federation of Engineering Institutions of South East Asia and the Pacific (FEISEAP) from

1992-94. He was elected a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE) in 1991 and served as Vice President from 1996-2000. In 2007 he was appointed founding Chairman of the ATSE Energy Forum, responsible for a number of high level sector reports and workshops.

In 1992 he was awarded the James Kirby Memorial Award of the Institution of Electrical Engineers and in 1998 the Medal of the Australian Institute of Energy (AIE), becoming the Institute's President from 2000 until 2002. He is past Chairman of the Australian National Team of the International Energy Agency's Centre for the Analysis of Energy Technologies (CADDET) and a past member of the ANC of the World Energy Council.

In 1995 he was appointed Chairman of the Olympic Energy Panel responsible for advising on energy efficiency and renewable energy use for the Sydney 2000 Olympic 'Green Games'. This task concluded with the highly successful Olympic and Paralympic events. In 2006 he was appointed Chairman of the CSIRO Energy Technology Science Review Panel, reporting to the CSIRO Executive on the Division's science quality. Later in 2006 he was appointed by the then Prime Minister to membership of Government's Uranium Mining, Processing and Nuclear Energy Review, producing the UMPNER Report.

Mr Thomas has served on a number of federal and state energy RD&D grant advisory panels, providing advice and recommendations on the assessment and allocation of program grants.

In 1993 he was appointed a Member of the Order of Australia for services to the engineering profession and to energy management. In 2003 he was awarded an Australian Centenary Medal for services to energy and engineering. In 2008 he was awarded the Peter Nicol Russell Memorial Medal of Engineers Australia, its highest award.