MANAGING CONCRETE PROBLEMS WITH PCE BASED ADMIXTURES

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ABSTRACT
Work to mitigate structural failures in concrete is a decades old endeavor. This work has culminated in a series of new raw materials. In turn these new materials have necessitated new chemistry in concrete admixtures. PCEs are a new generation of 3-dimensional comb-type polymers. The polymer chemistry can be used to customize admixtures to meet the needs of specific jobs. They have been frequently used to address many of the common as well as special site problems. In this paper, managing some concrete problems with the use of PCE based admixtures shall be discussed. Case studies from different parts of the world shall be presented.

CONCRETE: CURRENT & FUTURE TRENDS
Concrete is a versatile material, providing endless opportunities for those with imagination to exploit its properties. Extending and exploiting the versatility depends on improvements both in materials and mix design technology coupled with the production of consistently high quality products. Modification of the properties of concrete such as its rheological behaviour, setting characteristics, rate of strength development, heat evolution, durability and cost are commonly achieved using chemical and/or mineral admixtures. Concrete has been the major construction material in the past and is going to be with us for sometime to come. One of the main reasons for this is its continual adaptation to the ever changing demands. Admixtures have played a major role in upgrading the concrete quality & improving its versatility over the past several decades. Recent changes in availability and price of aggregates and cement have a significant effect in concrete production. Waste materials are more frequently used and recycling of building materials is becoming a hot topic due to environmental concerns. More recently, more prestigious projects with increasingly ambitious architectural concepts are being built. Thin shells, folded plates, and hyperbolic paraboloids have greatly extended and enhanced the visual appeal of concrete [1]. Longer pumping distances and stringent water tightness qualities are often needed. This has placed additional serious challenges on normal super-plasticized concrete. It is therefore more important now than ever before that admixtures be insensitive to quality changes in materials, and achieve fluid, stable, cohesive and durable concrete at even lower water additions.

WATER REDUCING ADMIXTURES: HISTORICAL BACKGROUND
Water reducing admixtures are the group of products which possess as their primary function the ability to enable the production of concrete at a lower w/c ratio, than that of a control concrete containing no admixture, at a given workability. Consequently, they allow considerable increase in strength or cement reduction and result in cost saving. Conversely they also give enhanced workability at a given w/c ratio. They are the most widely used class of concrete admixtures. The water reducing admixture group includes normal (neutral), accelerating & retarding, (Types A, E & D respectively). The latter two possess functions which could not be obtained by mix design considerations alone. The high range water reducing admixtures are an extension of the normal water reducing admixtures in that they are formulated from materials which allow much greater additions to be made without producing adverse effects. Using these, the concrete is produced having extreme workability at normal w/c ratios or very high strength at considerably lower water additions. These high range water reducing admixtures have been further classified into retarding (Type G to ASTM C494) & normal (Type F to ASTM C494).

The earliest known published reference to the use of small amounts of organic materials to increase the fluidity of cement containing compositions was in 1932 [2] when Condensates of Naphthalene Formaldehyde Sulphonate (NFSC) were claimed useful for this role. This was followed in the mid 1930's to early 1940's by numerous disclosures on the use of lignosulphonates as being useful. The application of Salts of Melamine Formaldehyde Sulphonate Condensate (MFSC) was not started until the 1960's. Lignosulphonates have traditionally formed the basis of the water reducers whereas NFSC and MFSC dominated the high range water reducers. The chemistry, applications and formulations of these polymers are well

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documented in the literature and they are often referred to as the 1st & 2nd generations of admixtures, respectively. The third generation PCE based admixtures were discovered in Japan in the late 1970s. This came about as it was found that the old generation of polymers, including those based on polyvinyl copolymer, could not fulfill the requirements needed from a modern superplasticiser (HRWR) such as the production of Self Compacting Concrete (SCC).

**ADMIXTURES FOR CONCRETE**

It could be said that the four most important potential properties of concrete are workability, durability, resistance to compressive stress & ability to protect steel from rusting. The first enables the material to be transported, handled or compacted into forms having any reasonable shape, whilst the second ensures a long life for the hardened mass; the third and forth form the basis of the design techniques which use the compressive strength of concrete together with the tensile strength of steel. However, to develop these properties fully requires concretes to be proportioned appropriately. Modifications afforded by the use of chemical admixtures have proved instrumental in governing these properties. The freshly mixed concrete must have the consistency to enable it to be transported from the mixer and readily compacted into the necessary moulds or forms. The hardened material must not only resist the stress imposed upon it, including those caused by climatic and other environmental conditions, but also the effects of any aggressive substances that are likely to come into contact with it. If steel is embedded in the mass to resist tensile stresses, the concrete must be impermeable to the agents which rust the steel. In this context, corrosion inhibitors have supplemented water reducers and proved useful in delaying the onset of corrosion and extending the service life of the structure [3].

To achieve durable concrete and structures, it is also necessary in the first place to select materials and mix proportions which, in hardened concrete, are inherently both physically and chemically resistant to their operating environment. However, this alone is not enough. The concrete must be designed such that it can be placed and compacted with minimum defects. The major underlying factors which govern these properties are compaction, workability, w/c ratio, maximum aggregate size, the size and grading of sand, the ratio of fine to coarse aggregate and the mix design. Chemical admixtures have played a major role in maintaining these properties. In addition, they have also achieved cost benefits by affecting the reduction of the overall cost of concrete ingredients, permitting rapid mould turn over, ease of placing and finishing, and reductions in cement or the use of blended cements or mineral additives [4].

High temperatures result in reduced workability and accelerated setting, with the increased risk of poor compaction or “cold” joints. Once the concrete is in place drying can occur, leading to plastic cracking. The high initial mix temperature accelerates the rate of hydration, resulting in high early temperature rise in cement rich or thick sections. This increases the risk of early thermal cracking and, while accelerating the early strength gain, may impair the long term development of strength and other properties, including those influencing durability. This in turn can cause premature deterioration of either the concrete itself or the reinforcement [5]. Water reducing retarders can contribute to quality, economy and ease of placing under these conditions. Low temperatures retard the setting and hardening of concrete and hydration virtually ceases at zero. When water freezes it expands generating internal stresses great enough to cause disruption. Anti-freeze and/or accelerating admixtures are beneficial in such circumstances. When accelerating admixtures are used the handling time of the concrete should be kept to a minimum. Air entrained concrete is more durable than non-air entrained concrete under the action of frost and the deicing salts which are used on roads and airfield pavements during winter. The air bubbles have a plasticizing effect on the mix, which usually necessitates some minor changes in mix proportions.

Concrete can be transported from a delivery point to a point of placing in a single operation with minimum labour, using pumping techniques. Normal concrete mixes resist being moved under pressure due to segregation of the cement paste that occurs when pressure is applied. Basically a pumpable concrete will have a suitable aggregate-void system and a cement paste consistency that will flow adequately through the void channels. Such requirements can often be met by specially designed mixes for individual jobs. However even with proper mix design the incidence of blockage is high. Many specifiers will not allow alterations to mix proportions merely to accommodate pumppability or low pumping pressures. A more viable option is offered by the use of chemical admixtures.
POLYCARBOXYLATE ETHER (PCE) BASED ADMIXTURES.

Chemical admixtures have played a key role in the past decades in improving the quality and upgrading the performance of concrete. Today they are required more than at any other time to be insensitive to quality changes in materials, and to achieve fluid, stable, cohesive, long pumping distances and durable concrete at low water additions. This is in addition to the production of self compacting concrete (SCC) which is rapidly spreading worldwide. The emergence of the third generation polycarboxylate ether (PCE) based admixtures have made it possible to meet such requirements, and address the many other site problems. While PCE based admixtures may sometimes come at a cost, the question, in the short term, should not be “can we afford to use them?” but “can we afford not to?” This can only be answered by recognizing the benefit in whole life cost which can be achieved, the many difficulties that can be overcome and the problems that can be solved.

Polycarboxylates (PCE), in particular, have gained wide acceptance as powerful dispersants in admixtures [6]. The polymer chemistry can be used to customize admixtures to meet the needs of specific construction jobs. They are the third generation of water reducers and are manufactured by the combination of a number of building blocks which are synthesized by polymerization. The new generation comb-type polycarboxylate polymers are ideal for:

- Powerful plasticizing, leading to increased strength
- Special formulations to keep concrete cohesive and homogeneous.
- Controlled workability.

A greater water reducing effect in concrete can be obtained by enhanced dispersibility and stable dispersion of the cement particles. The retention of dispersion of inorganic microparticles is due to electrical and steric repulsion of the adsorbed surfactant. Their chemical and physical properties are controlled by:

- Backbone
- Side chain length & density
- Electric Charges, and
- Functional groups of the polymer.

It is therefore clear that the polymer chemistry can be used to customize admixtures by regulating the above parameters or other variables to meet the needs of specific construction jobs. PCEs can be made by design to affect water reduction and workability retention, and can also be formulated to keep the concrete cohesive and homogeneous. Stable dispersion due to electrical repulsion can be explained by the well known DLVO theory. The greater this energy barrier the more stable the dispersion, which is found to correlate well with the value of the zeta potential [7]. The repulsion due to the steric effect can be explained by entropy effect theory. The water reducing effect of cement composites such as concrete is obtained by increasing the dispersion of the cement particles. Water reducing agents are roughly divided into two types, those which enlarge the zeta potential and increase the repulsion and those which increase the force of repulsion by sterically expanding the adsorption layer. Melamine & naphthalene sulphonate formaldehyde condensate based water reducers are adsorbed in the shape of a rod in several layers, and the cement particles are dispersed due to the strong electrical repulsion of the negative ions of the sulfonate group. The size of this repulsion can be estimated by measuring the zeta potential of the surface of the cement particle. For polycarboxylate based water reducing agents, cement particles are dispersed and the water reducing effect is obtained by the electrical repulsion of the negative ions of the carboxylic group and steric repulsion of the main and side chains. Therefore PCE based water reducing agents can give water reductions equal to that of the conventional admixtures at much lower dosages or much higher water reduction at equal dosages.
Conventional High Range Water Reducers disperse the cement particles through electrical repulsion giving water reductions of up to 20%.

The Sika technology of PCE based admixtures was introduced in the late nineties [6, 8], and many projects around the world have been executed using it, giving solutions to many difficult problems. In the next few pages some challenges are highlighted and the solutions provided by the use of PCE based admixtures, through the maximization of design freedom, enhanced concrete placement leading to increased productivity and enhanced overall working environment, are discussed.

The new generation three dimensional comb-type polycarboxylate polymers disperse the cement particles through a double action of electrical repulsion and steric hindrance resulting in higher water reductions (up to 40%) and much longer slump retentions.
**SELECTED CASE STUDIES:**

**Challenge 1: Vertical & long distance pumpability**

1.1 **Cut and Cover Tunnel in SMART**

1.1a SMART stands for Stormwater Management And Road Tunnel. Two objectives:

1) To channel stormwater from the Klang & Ampang rivers to the Taman Desa retention pond.

2) Part of the tunnel will also be used as a motorway when not fully flooded.

**Project details**
- Project Cost RM 2.5bn (US$0.7bn)
- 9.7km water-cum-motorway tunnel
- 4km motorway - 49,000 cars per day
- 15 mins to clear traffic: fully used to channel floodwater.
- Completion scheduled for 2007

![SMART Tunnel route. Inset showing the two deck, three chamber tunnel.](image1)

**1.1.b Requirements**
- Concrete Grade 40
- High workability of the concrete
- Pump mix design
- Long slump life
- Initial slump < 200 mm
- Minimum slump at 2 hrs = 125 mm
- Reduction in cement (desirable)
- Single admixture (desirable)
- High placing temperatures

**1.1.c Concrete mix design**
- Mascrete 390 kg/m³
- Coarse Agg. 974 kg/m³
- Sand 834 kg/m³
- Water 156 litres/m³
- Admixture (PCE) @ 2 lit/m³

**1.1.d Typical Results:**
- W/C ratio = 0.4
- Initial slump = 180 mm
- Slump at 2 hrs = 120 mm
- Good pumpability at low pump pressure
- Compressive strength (target + margin achieved)
- Cement reduction achieved
- Single admixture
- Competitive price

![First trial pour of 400 m³](image3)
1.2 Project: 450 m high building in Hong Kong

1.2a Requirements:
- SCC, C100 concrete
- Low and stable concrete viscosity
- To be pumped up to 480 m high
- Constant slump life for 180 min even after pumping

1.2b Mix design:
- OPC 358 kg/m³
- PFA 192 kg/m³
- M/silica 42 kg/m³
- 10 mm 1000 kg/m³
- R sand 680 kg/m³
- Water 130 kg/m³ (w/b = 0.21)
- Admixture (PCE) @ 6 lit/m³

1.2c Results:

Figure 4: Initial Slump Flow

Figure 5: Slump Flow after pumping 450m up and 170 min. No bleeding or segregation.

1.3 Long distance pumpability

1.3a Project: SMART Road Deck - Malaysia

1.3b Requirements:
- Internal concreting for decks & walls pumped from tunnel shaft
- Pumping distance up to 1500 m!
- Concrete Grade 40
- Initial slump = 220 mm
- Slump at 3 hrs not less than 160 mm
- 24 hr strength = 14 N/mm²

1.3c Mix design:
- Mascrete 380 kg/m³
- LSP 40 kg/m³
- C. Agg. 940 kg/m³
- Sand 801 kg/m³
- Water 172 kg/m³
- Admixture (PCE) @ 2.3 lit/m³

1.3d Long Distance Pumping Trial
Batch slump - 200mm, started pumping after 40 mins
- 200m length – Slump 200mm - Conc Temp 30°C
- 600m length – Slump 200mm
- 1000m length – Slump 160mm
- 1400m length – Slump 155mm
- 2000m length – Slump 140mm - Conc Temp 34°C
Initial set: 5 hours, Final set: 6.5 hours
24 hour strength 14 MPa
Challenge 2: Water tight concrete to replace external membranes

2.1 Watertight Tunnel

2.1a Project: Watertight KLCC Tunnel - Malaysia
This tunnel connects KLCC towers with KLCC convention centre.

2.1b Requirements
- Replace external Waterproofing Membrane with high-performance Watertight Concrete.
  - Permeability & absorption specified.
- Eliminate potential workmanship problems with concrete placement and waterproofing installations.
- 28day Compressive Strength:
  - Min 50 N/mm²
- Hotel proximity to Site: Reduce or eliminate noise
  - Self-Compacting Concrete
  - Flow: Min 600mm @ 2hours

2.1b: Mix Design
- Low heat Mascrete 450 kg/m³
- Sand 700 kg/m³
- 20mm aggregate 595 kg/m³
- 10mm aggregate 455 kg/m³
- w/c ratio 0.35
- Admixture (PCE based) 1.5% bwoc
- Integral waterproofing admixture 1.5% bwoc
- Viscosity Modifying Agent 0.6% bwoc

2.1c Results
SCC used to construct all floors, walls and soffits of tunnel. The mix design included an integral waterproofing admixture and a viscosity modifying agent to give the mix more cohesion and avoid any bleeding and segregation.

Hardened concrete achieved both permeability (RPC < 1000 coul.) & absorption (< 2%) to BS 1881 specification allowing the elimination of waterproofing membranes in tunnel construction.
Challenge 3: Nonstop pouring of 28,000 m\(^3\) of uniform quality concrete:

3.1 Project: Mori Tower – Shanghai, China

3.1a Project details
- Project period: end 2004 - end 2007
- High-rise building: 492 m high
- 101 floors above ground with 3 basements plus a foundation with depth of 4.5 m – 4.7 m
- Total concrete volume: 300,000 m\(^3\) including SC & CFT from grades C30 to C60.
- Admixture: PCE based 1,200 tons in total

3.1b Requirements

Table 1: Three foundation concrete pours with congested reinforcement

<table>
<thead>
<tr>
<th>Concrete Pouring</th>
<th>Date Started</th>
<th>Hours of Pouring</th>
<th>Involved</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RMC plants</td>
</tr>
<tr>
<td>1 4,000 m(^3)</td>
<td>26/12/04</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>2 4,500 m(^3)</td>
<td>08/01/05</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>3 28,000 m(^3)</td>
<td>28/01/05</td>
<td>40</td>
<td>7</td>
</tr>
</tbody>
</table>

3.1c Mix Design & Results:
- OPC 270 kg/m\(^3\)
- PFA 90 kg/m\(^3\)
- Slag 70 kg/m\(^3\)
- Sand 715 kg/m\(^3\)
- Aggregate (5-25 mm) 1029 kg/m\(^3\)
- Water 170 kg/m\(^3\)
- Admixture (PCE): 0.8% by wt. (OPC + Slag)
- Designated initial slump 200 mm
- 2-hr slump 150±30 mm

Figure 13: Trucks queued for turn
Figure 14: More than 6 pumps working simultaneously
Figure 15: Congested reinforcement
Figure 16: Normal slump concrete flowing with a bit of help to spread the concrete
CONCLUSIONS:

- The use of PCE based admixtures has allowed the optimization of concrete properties and has lead to incremental advances in design and placement of concrete, such as long distance pumpability, water tightness and long slump retentions at low water additions.

- PCE based admixtures have maximized the design freedom leading to the production of SCC, CFT and ultra high strength concrete. SCC can eliminate or drastically reduce the need for vibration, saves time making it possible to reduce labour costs while improving the overall work environment and gives higher casting guarantees of uniformity and quality even of complex shapes.

- Faster placement, reduced construction time and less finishing time can improve productivity and profitability. Increased flowability and consolidation can improve appearance and enhance the durability of finished elements.

REFERENCES


8. Abdelrazig, B.(2004) “A contribution towards the study on: developing applications of SCC to enhance quality, cost effectiveness, buildability and to reduce noise in public housing construction by City University of Hong Kong” Sika Internal publication.