

ReBuild

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HEALING AND SELF-HEALING OF CONCRETE AND STONE

Dr. Fixit Institute
of Structural Protection & Rehabilitation

A Not-for-Profit Knowledge Centre

Can Concrete be a 'Smart' Material?

It is important to note that the IT age has not left engineered materials 'dumb'. Dumb materials and structures contrast sharply with the natural world where the animals and plants have the clear ability to adapt to their environment in real time. The field of biomimetics, which looks at the extraction of engineering design concepts from the biological materials and structures, has much to teach us on the design of future man-made materials. The process of balance is a truly 'smart' or 'intelligent' response, allowing, in engineering terms, a flexible structure to adapt its form in real time to minimize the effects of an external force, thus avoiding catastrophic collapse. The materials and structures involved in natural systems have the capability to sense their environment, process this data and respond. Thus, the real 'smart' materials integrate information technology with structural engineering followed by actuation and locomotion.

There are many possibilities for such materials and structures in the man-made world. Engineering structures could operate at the very limit of their performance envelopes and to their structural limits without any apprehension of exceeding either. These structures could also give the maintenance engineers a full report on performance history, as well as the location of defects, whilst having the ability to counteract unwanted or potentially dangerous conditions such as excessive vibration, and cause self-repair. Smart materials and structures are sometimes termed as 'sensual' devices, as they can sense the environment and generate data for use in "Health and Usage Monitoring Systems (HUMS)". Currently the commonest application of HUMS is in aerospace engineering and aircraft checking.

It is progressively unfolding that the monitoring of the civil engineering structures can also be undertaken by constructing 'sensual structures'. The current and long-term behaviour of a bridge can be monitored, resulting in enhanced safety during its life. This can happen by taking note of early warnings of structural problems at a stage where minor repairs would enhance durability. The above

example emphasizes only 'sensual' function. Smart materials and structure not only 'sense' but also 'adapt' to their environment.

Worldwide, considerable effort is being made to develop smart materials and structures. The latest in the run is to design and produce "Smart Concrete". A paper on research authored by Deborah Chung of the University of Buffalo (USA) claims the following: "A highway made with smart concrete would be able to tell where each vehicle was, and what its weight and speed were". This type of concrete is made by reinforcement using short carbon fibres in order to modify the electrical resistance of concrete and to cause response to strain or stress. Such research is expanding the horizon of smart concretes as, apart from carbon fibres, carbon black, steel slag, nanophase materials, etc. can also be added to provide better ability of concretes to sense stress and strain in them compared to normal concrete.

One of the intrinsic problems of concrete is its proneness to crack. In order to overcome this problem, a variant of smart concrete is rapidly developing, which is known as "self-healing" concrete. The self-healing concrete is one that senses its crack formation and reacts to cure itself without human intervention. Various materials and technologies are being tried out to achieve the above objective. Since it is a high potential research area for ensuring concrete durability, we, at Dr. Fixit Institute of Structural Protection and Rehabilitation, had invited Professor Nele DeBelie of Ghent University, Belgium to deliver an enlightening talk on self-healing concrete, which was well appreciated by the professional engineers, architects and academics.

In this issue of 'Rebuild', we have attempted to capture and disseminate an excerpt of her talk as well as of some relevant publications on the subject.

We hope that our readers will find this issue interesting.

Special Lecture delivered by Dr. Nele De Belie, Ghent University, Belgium on "Healing and Self-Healing of Concrete and Stone"

1.0 Introduction

Concrete plays a major role in the construction industry. For a durable structure, good quality concrete must be used. In the life cycle of a structure, concrete and stone gets affected by physical, chemical and environmental factors. Concrete structures are affected by cracking, spalling, etc. The cracks are formed by thermal expansions, external loads, temperature variations and other environmental factors.

Prof. Nele De Belie has shown during her presentation how repair and consolidation of mineral phases of building materials and the healing and self-healing of concrete with the help of bacteria is possible.

2.0 Healing and Self-Healing

2.1 Consolidation of Mineral Phases of Building Material

Consolidation means reduction of the porosity of the structure and densification of the structure. The building materials deteriorate due to weathering actions such as physical, chemical and biological actions. The building materials also deteriorate due to interaction of micro-organisms with stone and concrete. Micro-organisms play a crucial role in pedogenesis, transformation of minerals and exchange of elements in structures. This also includes transformation of hard rocks to soft soil, which supports plant growth and is a positive process in nature. However, when this rock is used as a building block or a constituent of concrete, this biodegradation process is far from positive. The building materials may be protected by traditional systems such as coatings and hydrophobic sealers or with organic dispersions, but this has the following disadvantages:

- The surface layer will have a different thermal expansion coefficient compared to concrete.
- Formation of incompatible surface film.
- Environment and health hazards.

On the other hand the micro-organisms such as bacteria, cyanobacteria, algae, lichens, yeasts, fungi and mosses etc., which are omnipresent and omnipotent, are responsible for metabolism action that results in a microbial deposition of a protective CaCO_3 layer. Also, this process results in re-establishment of the cohesion between particles of mineral building materials and protects against further decay of stone material. To prove the positive effects of microbial CaCO_3 precipitation, the micro-organisms were applied on concrete or stone samples by a subsequent immersion with following procedure:

- The sample is immersed up to 1 cm depth for 1 day in bacteria culture.
- Subsequently placed for 3 days in biodeposition medium.
- Lastly treated for 7 days by drying at 28°C.

This treatment results in precipitation of carbonate crystals which can be seen by a scanning electron microscope or thin section (Fig. 1). This precipitation of carbonate crystals was not limited to the outer surface only, but could be observed at depth greater than 1 mm and bacterial cells could be observed clearly.

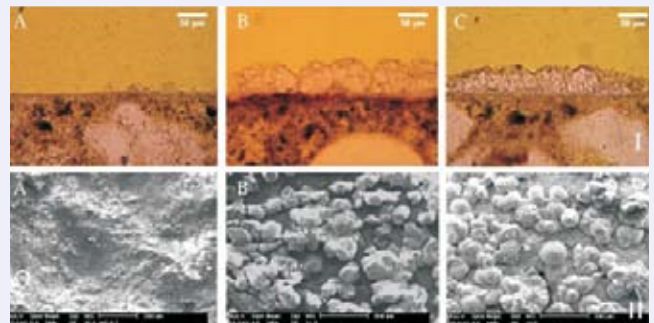


Fig. 1: Thin sections (top) and scanning electron microscopic views (bottom) of (A) untreated (B) biodeposition with CaCl_2 and (C) biodeposition with Ca acetate

The increase in porosity in concrete leads to increase in capillary water uptake, increase in gas permeability along with higher carbonation rate, higher chloride migration and freeze-thaw damage. But precipitation of carbonate crystals by using *Bacillus Sphaericus* isolates with calcium acetate or calcium chloride as a calcium source (*Bac.sph. Ca Ac* & *Bac.sph. CaCl₂*) helped to decrease the capillary water uptake in concrete up to 65-90% (Fig. 2) and minimized the water absorption. It helped to decrease porosity and gas permeability. Also, biodeposition of micro-organisms (*Bac.sph. Ca Ac* & *Bac.sph. CaCl₂*) helped to increase the resistance towards carbonation and the rate of carbonation decreased up to 25-30% (Fig. 3) and the decrease in chloride migration amounted up to 10-40%. All these helped to achieve a durable structure.

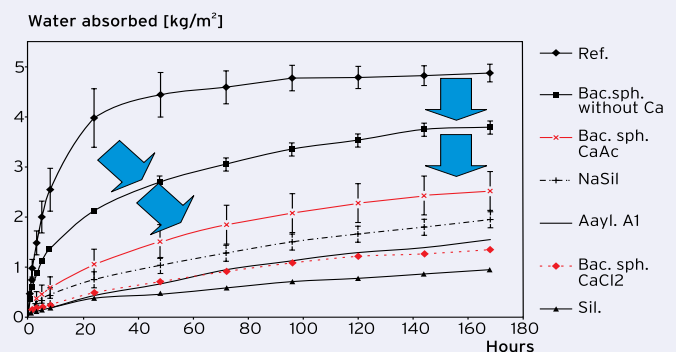


Fig. 2: Biodeposition resulted in decrease in capillary water uptake in concrete

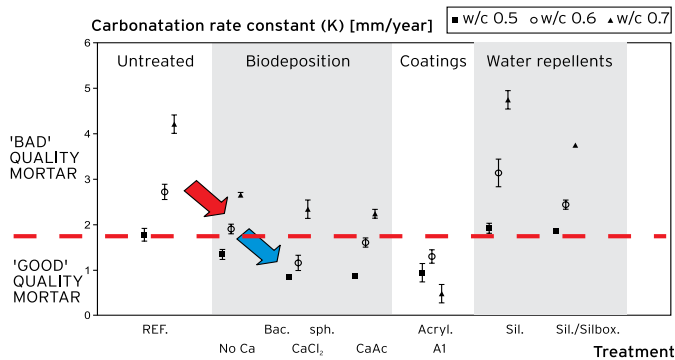


Fig. 3: Biodeposition increased resistance towards carbonation



Fig. 4: Crack repaired with epoxy

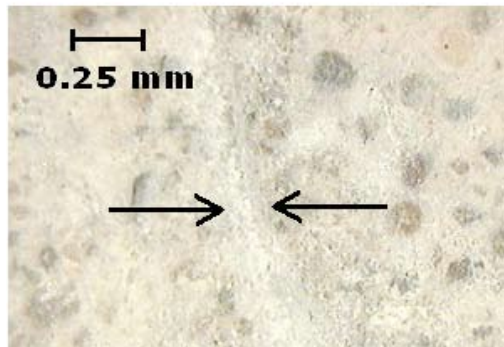


Fig. 5: Crack repaired with bacteria in Sol-gel medium

2.2 Healing of Cracks in Concrete

For remediation of cracks, usually traditional repair methods such as grouting or epoxy injection (Fig. 4) are being used. But the latest development of bacterial treatment is more useful. In the bacterial treatment, the solution medium used was of equimolar concentration of urea (20g/l) and CaCl_2 or $\text{Ca}(\text{NO}_3)_2$ for 3 days and thereafter dried for 3 days at 28°C. The bacteria used were *B. Sphaericus*(BS). But to protect these bacteria from the strong alkaline environment in concrete, they were immobilized in Silica Sol-gel (Fig. 5). The treatments were applied by placing the samples on plastic rods in the treatment solution, where the liquid level was 10 mm above their lower side. Remediation of cracks could be possible by formation of biocers (in contact with a salt, the silica

sol becomes a silica gel, creating a biological ceramic material) together with carbonate precipitation inside. By this process the cracks up to 10 mm deep could be completely filled (although this could not seal a 20 mm deep fissure completely). This also helped to decrease the water permeability.

2.3 Self-Healing of Cracks in Concrete

In concrete, cracking is a common phenomenon due to the relatively low tensile strength of this material. As these cracks function as an entry channel for potentially aggressive liquids and gases, which may cause concrete attack and reinforcement corrosion, they need to be repaired. However, large costs are involved in maintenance and repair of concrete structures. Besides, indirect costs are even 10 times higher than the direct costs of maintenance and repair.

Therefore, it would be interesting to design the material in such a way that it repairs the damage all by itself. Self-healing properties may be obtained when encapsulated healing agents are dispersed through the concrete matrix. Once a crack appears, the capsules break and the healing agent is released into the crack, resulting crack repair. The other method of self-healing is introducing healing agents in glass tubes dispersed through the concrete matrix. Cracks form in the concrete matrix wherever damage occurs and subsequently these cracks break the glass tubes, releasing both components of the healing agent into the crack plane through capillary action. When both components come into contact, the polymerization reaction is triggered and the crack faces are bond together.

The concrete can be provided with a self-healing mechanism by using healing agents such as polyurethane. The concrete has to be filled throughout the matrix with polyurethane in capsules. The capsules used were made of ceramic tubes of 3 mm dia. and 100 mm long or glass tubes of 2 mm or 3 mm dia. having the same internal volume (Fig. 6). The components used as healing agents were prepolymer of polyurethane on the one hand and a mix of accelerator and water on the other hand. Upon polymerization reaction (Fig. 7), the concrete regained its mechanical properties due to crack healing as confirmed by bending test. Due to crack healing water permeability also decreased.



Fig. 6: Capsules of ceramic tubes



Fig. 7a: PU healing agent before polymerization



Fig. 7b: PU healing agent after polymerization

For self-healing of concrete, concrete beams with and without autonomous crack healing properties were tested. The concrete beams had size (500 mm X 110 mm X 50 mm) with a 20 mm-deep notch in the middle and the self-healing beams contained the tubular capsules filled with a mix of accelerator and water and prepolymer of polyurethane. Concrete beams were subjected to three-point bending test, which resulted in crack formation and healing. For comparison, some beams were made without self-healing properties and the cracks were repaired manually. In case of manually-healed cracks, the crack should be injected by polyurethane after the bending test and in case of autonomous crack healing, the polyurethane was released automatically during the bending test. The beams were reloaded in three points bending to determine the amount of regain in strength due to crack healing. Due to autonomous crack healing, 90% strength regain and 60% regain in stiffness were obtained (Fig. 8) This also helped to decrease the water permeability.

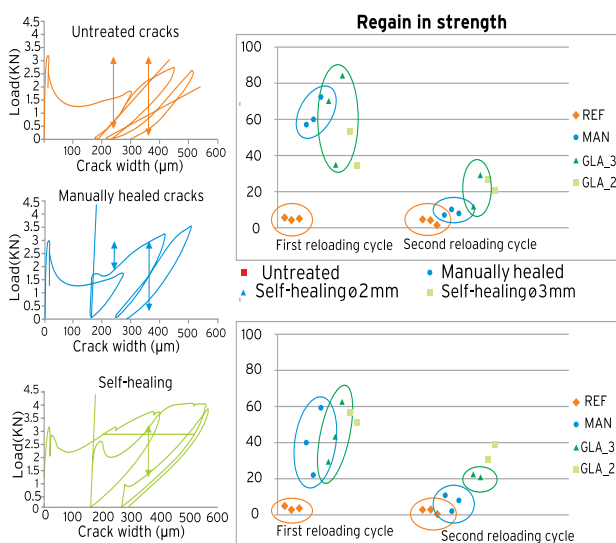


Fig. 8: Regain in mechanical properties due to crack-healing

REF: Untreated samples

MAN: Manually healed cracks

GLA_2: Self-healing by 2 mm ϕ glass tube

GLA_3: Self-healing by 3 mm ϕ glass tube

After the first reaction of healing, a second reloading can be carried out and a second healing action can be feasible with a liquid healing agent or polyurethane foam. To prove the

crack healing efficiency by means of acoustic emission measurements, the beams were subjected to a crack width controlled bending test, while acoustic emissions were captured and, upon crack healing, the beams were reloaded to test the possibility to prove crack healing again by means of acoustic emission test.

As another option for self-healing of concrete, bacteria spores were used. To protect the bacteria from higher alkalinity of the concrete, the carrier materials used in tubes were PU (Polyurethane) and SG (Silica Gel). The components used for self-healing were the following:

- Bacteria to precipitate CaCO_3 crystals - Bacillus Sphaericus
- Calcium source / salt for gel formation - $\text{Ca}(\text{NO}_3)_2$
- Nutrients - Urea
- Protection against concrete envelope - SG/PU
- Trigger mechanism - Breakage of glass tubes

Argex and Lava were also used to test as other suitable carrier materials in self-healing action of concrete. Lava could improve the performance where as in case of argex the strength reduced in comparison with standard reference specimen for testing compressive and tensile strength of such samples. By self-healing of concrete, strength regained after cracking and cracks were sealed immediately by which aggressive substances would not enter through the cracks and more durable concrete structures could be obtained.

3.0 Conclusion

Crack repair with a biological treatment in which a *B. sphaericus* culture is incorporated in a gel matrix is most effective. Silica gel can be used to protect the bacteria against the high pH in concrete. This helps to decrease in water permeability. Precipitation of these crystals inside the gel matrix also enhances the durability of this repair material. The use of this biological treatment is highly desirable because the mineral precipitation induced as a result of microbial activities is pollution-free and natural. Self-healing of cracks in concrete is due to embedding encapsulated healing agents in concrete resulting following:

- Strength regain after cracking
- Cracks are immediately sealed
- Aggressive substances will not enter the cracks
- More durable concrete structures
- Regain of water impermeability could still be improved

Biological approach for healing and self-healing of cracks in concrete and consolidation of building materials can be possible by adopting this latest green technology, which makes the structures durable and environment friendly.

[Lecture was delivered on Healthy Construction Lecture Series organised by Dr. Fixit Institute of Structural Protection & Rehabilitation, Mumbai by Prof. Nele De Belie, Magnel Laboratory for Concrete Research, Dept. of Structural Engineering, Ghent University, Belgium at Kolkata and New Delhi on 23rd and 24th September, 2010 respectively]

Self-Healing of Concrete - A New Technology for a More Sustainable Future

[Extracted from website <http://www.swieet2007.org.uk/files/Self-Healing-Concrete.pdf> and http://en.wikipedia.org/wiki/Self-healing_material]

1.0 Introduction

Self-healing materials are a class of smart materials that have the structurally incorporated ability to repair damage caused by mechanical usage over time. The inspiration comes from biological systems, which have the ability to heal after being wounded. Initiation of cracks and other types of damage on a microscopic level has been shown to change thermal, electrical, and acoustic properties, and eventually lead to total failure of the material. Usually, cracks are mended by hand, which is difficult because cracks are often hard to detect. A material (polymers, ceramics, etc.) that can intrinsically correct damages caused by normal usage could lower production costs of a number of different industrial processes through longer service life, reduction of inefficiency over time caused by degradation, as well as avoidance of costs incurred by material failure. For a material to be defined as self-healing, it is necessary that the healing process occurs without human intervention. Researchers are taking both chemically and biologically-based approaches to create concrete that heals itself. Chemical approaches typically use outside or embedded water supplies to activate dry cement grains, while biologists are looking at bacteria to fill the pores.

1.1 Liquid-Based Healing Agents

Completely autonomous, synthetic self-healing material was reported in 2001 with an example of an epoxy system containing microcapsules. These microcapsules were filled with a (liquid) monomer. If a micro crack occurs in this system, the microcapsule will rupture and the monomer will fill the crack. Subsequently it will polymerise, initiated by catalyst particles (Grubbs catalyst) that are also dispersed through the system. This model system of a self-healing particle proved to work very well in pure polymers and polymer coatings.

A hollow glass fibre approach may be more appropriate for self-healing impact damage in fibre-reinforced polymer composite materials. Impact damage can cause a significant reduction in compressive strength with little damage obvious to the naked eye. Hollow glass fibres containing liquid healing agents (some fibres carrying a liquid epoxy monomer and some the corresponding liquid hardener) are embedded within a composite laminate.

1.2 Solid-State Healing Agents

In addition to the sequestered healing agent strategies

described above, research into 'intrinsically' self-healing materials is also being performed. For example, supramolecular polymers are materials formed by reversibly-connected non-covalent bonds (i.e. hydrogen bond), which will disassociate at elevated temperatures. Healing of these supramolecularly-based materials is accomplished by heating them and allowing the non-covalent bonds to break. Upon cooling, new bonds will be formed and the material will potentially heal any damage. An advantage of this method is that no reactive chemicals or (toxic) catalysts are needed. However, these materials are not "autonomic" as they require the intervention of an outside agent to initiate a healing response.

1.3 Biomimetic Design Approaches

Self-healing materials are widely encountered in natural systems, and inspiration can be drawn from these systems for design. There is evidence in the academic literature of these biomimetic design approaches being used in the development of self-healing systems for polymer composites.

2.0 Self-Healing of Cementitious Composites

The development of self-healing cementitious composites is a relatively new area of research, which to this date has focused both on the natural ability of hydrates to heal cracks over time (autogenous) and artificial means of crack repair that are man-made inclusions (autonomous). The motivation for such work is to increase the durability of concrete.

The natural self-healing ability of concrete, known as autogenous healing, has been understood for around 20 years. The effect can be seen in many old structures, which have survived for such long periods of time with only limited maintenance. Cracks in old concrete structures such as Roman aqueducts and Gothic churches have been seen to heal when moisture interacts with unhydrated cement in the crack. However, in recent structures the cement content is reduced due to modern construction methods and hence the amount of available unhydrated cement is lower and the natural healing effect is reduced. The three main processes of autogenous healing are (i) swelling and hydration of cement pastes; (ii) precipitation of calcium carbonate crystals, and; (iii) blockage of flow paths due to deposition of water impurities or movement of concrete fragments that detach during the cracking process. Numerous authors in recent years have investigated various situations that affect the amount and rate of autogenic healing including the effect of temperature, degree of damage, freeze-thaw cycles and the age of the concrete. The mix composition of the mortar can also be used to enhance the autogenic behaviour, for example by including blast furnace slag into the mix. It was found that maximum healing occurred in early age concrete and specimens

tested under water showed the best strength recovery, hence it was concluded that the primary healing mechanism was ongoing hydration.

The simplest way of self-healing is to ensure that extra dry cement in the concrete exposed on the crack surfaces can react with water and carbon dioxide to heal and form a thin white scar of calcium carbonate. Calcium carbonate is a strong compound found naturally in seashells. In the lab, the material requires between one and five cycles of wetting and drying to heal.

There have been a number of healing agents proposed. However, these are generally 'off the shelf' agents, making them relatively low cost and readily available. This suits the nature of their use in large bulk material such as concrete. To date, the most common healing agents proposed are epoxy resins, cyanacrylates, and alkali-silica solutions. There are a number of pre requisites that an agent must possess including, a suitably low viscosity to ensure a wider repair area and a sufficiently strong bond between crack surfaces and that there should be adequate capillary forces to draw the agent into the crack.

2.1 Materials

2.1.1 Epoxy Resin system

In epoxy resin system, a low viscosity epoxy resin in an organic film pipe that melts at 93°C. Upon formation of a crack, sensed via a strain gauge, there is a reduction in electrical conductivity and hence increased resistance and temperature. This increased temperature melts the organic supply tube and cures the epoxy resin after it has flowed into the crack.

2.1.2 Cyanoacrylates

Commonly known as super glues, cyanoacrylates are a one part system that, in the presence of moisture, react and cure very rapidly forming a bond often stronger than the material it is bonding, i.e. concrete. Hence the healed crack is actually stronger than the surrounding material itself. This system showed that if a system is damaged and healed and then damaged again, a new crack will form around the healed crack. The use of cyanoacrylates in concrete is further enhanced by them being an acidic solution, which due to the concrete's alkaline environment causes yet quicker healing.

2.1.3 Alkali-Silica Solutions

Alkali-silica solutions have also been utilized as healing agents mainly; in the presence of oxygen, the solution causes hydration and hence bonding of the original crack faces. Although this system produces lower bond strength, it causes less material compatibility problems than the previous two systems.

The above described healing agents require a method

to encapsulate them in the cementitious matrix until they are required for healing. The above 1-component healing agents are preferable than 2-component healing agents because of incomplete mixing of the different components. But the 1-component healing agent has a shorter shelf life period. 2-component polyurethane healing agent has been used quite successfully. Several methods have been proposed including the use of microcapsules, a continuous glass supply tube and capillary tubes, which are embedded in the concrete.

2.2 Method of Encapsulation

2.2.1 Hollow Tube Approach

Fragile glass capillaries or fibers are embedded within a composite material. The resulting porous network is filled with monomer. When damage occurs in the material from regular use, the tubes also crack and the monomer is released into the cracks. Other tubes containing a hardening agent also crack and mix with the monomer causing the crack to be healed. The diameter of the tube is 20-70 μm and the material for tube is urea formaldehyde or gelatin. Capillary tubes used in the medical profession for blood testing have been embedded in concrete as encapsulating vessels for ethyl cyanoacrylate healing agent. Experiments have that despite some localized debonding between the tube and cement matrix, the system was successful in sensing crack propagation and actuating accordingly healing the crack. Finally, continuous glass supply pipes which have the advantage of being able to vary the healing agent and supply additional healing agent have proven successful in healing larger fractures. The issue with such a system, however, is that care must be taken in placing the glass tubes and hence is not suitable for cast in-situ concrete.

2.2.2 Microcapsule Healing

This method is similar in design to the hollow tube approach. Monomer is encapsulated and embedded within the thermosetting polymer. When the crack reaches the microcapsule, the capsule breaks and the monomer bleeds into the crack, where it can polymerize and mend the crack (Fig. 1)

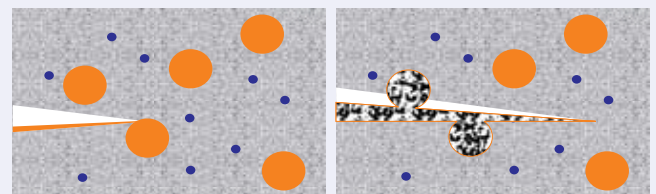


Fig. 1: Depiction of crack propagation through microcapsule-embedded material

Orange circles - Monomer microcapsules

Blue dots - Catalyst

In order for this process to happen at room temperature, and for the reactants to remain in a monomeric state within the capsule, a catalyst is also imbedded into the thermoset. The catalyst lowers the energy barrier of the reaction and allows the monomer to polymerize without the addition of heat. The capsules (often made of wax) around the monomer and the catalyst are important to maintain separation until the crack facilitates the reaction. Microcapsules have the advantage that the concrete can react to diffused cracking in multiple locations, although once a capsule has "been utilized" it cannot be refilled and it remains a void in the concrete.

3.0 Cementitious-Shape Memory Polymer Composite System

Another system being developed at Cardiff University combines both the autogenous healing and autonomous principles in that it makes use of a man-made system to enhance the natural autogenous healing and repair cracks in concrete. The system incorporates shape memory polymers into the cementitious matrix to place the crack in the most favourable conditions for autogenous healing to occur.

The cementitious-shape memory polymer composite system being developed at Cardiff University is based on polyethylene terephthalate (PET) polymer material. Shape memory polymers are semi-crystalline polymers which have a predefined shape memorised in their material structure. In the case of the proposed system the memorised state is a shorter specimen than the current material, so that upon activation the specimen will contract or shrink and in a restrained condition generate a shrinkage force.

Upon crack formation the system seen in Figure 2 will be triggered. The shape memory polymer, which is anchored within a cavity in the cementitious matrix, is activated via heating. Heating can be in the form of direct heat or electrical current via an increase in temperature due to high ohmic resistance. Upon activation the shape memory effect or shrinkage occurs and due to the restrained nature of the tendon, a tensile force is generated. This tensile force in turn imparts a compressive force to the cementitious matrix at the crack location and hence the crack closes. Autogenous healing then occurs and is enhanced by the crack being put into this compressive state.

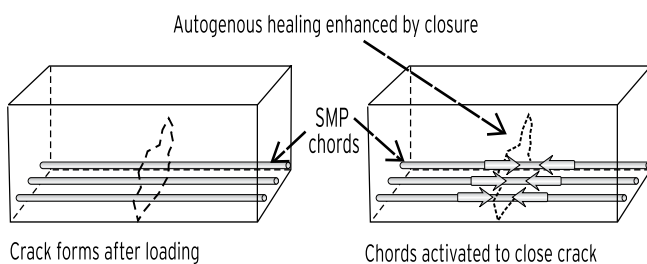


Fig.2: Shape-memory polymer-cementitious composite

4.0 Inorganic Self-Healing Material

Another inorganic self-healing material is being developed at the University of Rhode Island, where micro-encapsulated sodium silicate healing agents of small amount (about 2%) are directly embedded into a concrete matrix. When tiny stress cracks begin to form in the concrete, the capsules rupture and release the healing agent into the adjacent areas. The sodium silicate reacts with the calcium hydroxide naturally present in the concrete to form a calcium-silica-hydrate product to heal the cracks and block the pores in the concrete. The chemical reaction creates a gel-like material that hardens in about one week. The special feature of this material is that it can have a localized and targeted release of the healing agent only in the areas that really need it. Figure 3 shows one such concrete matrix embedded with micro-encapsulated sodium silicate healing agent for self-healing, which additionally acts for waterproofing.



Fig. 3: Concrete matrix embedded with a micro-encapsulated sodium silicate healing agent

In tests comparing a standard concrete mix to concrete containing two percent sodium silicate healing agent, sodium silicate healing mix recovered 26 percent of its original strength (after being stressed to near breaking) versus just 10 percent recovery by the standard mix. This healing agent could also act as a corrosion inhibitor. The release of the agent will result in corrosion inhibition by two mechanisms. First, the reduced water transport due to the filled pores and reduced interconnectivity within the matrix may result in less moisture reaching the metal and ultimately less corrosion. Also, silicates can deposit on the surface to form a protective film, which may also help with reducing the corrosion rate of the steel rebars. The effectiveness to use as additional corrosion inhibitor is still in research stage.

5.0 Catalyst-Free Self-Healing Material System

A new catalyst-free, self-healing material system developed by researchers at the University of Illinois offers a far less expensive method and the

new self-healing system incorporates chlorobenzene microcapsules, as small as 150 microns in diameter, as an active solvent. The expensive, ruthenium-based Grubbs' catalyst, which was required earlier, is no longer needed. By removing the catalyst from the material system, a simpler and more economical alternative could be developed for strength recovery after crack damage has occurred. Self-healing of epoxy materials with encapsulated solvents can prevent further crack propagation while recovering most of the material's mechanical integrity. During normal use, epoxy-based materials experience stresses that can cause cracking, which can lead to mechanical failure. Autonomous self-healing is a process in which the damage itself triggers the repair mechanism to retain structural integrity and extend the lifetime of the material. This system of self-healing system is simple, very economical and potentially robust.

In the researchers' original approach, self-healing materials consisted of a micro-encapsulated healing agent (dicyclopentadiene) and Grubbs' catalyst embedded in an epoxy matrix. When the material cracked, microcapsules would rupture and release the healing agent, which then reacted with the catalyst to repair the damage. In their new approach, when a crack forms in the epoxy material, microcapsules containing chlorobenzene break. The solvent disperses into the matrix, where it finds pockets of unreacted epoxy monomers. The solvent then carries the latent epoxy monomers into the crack, where polymerization takes place, restoring structural integrity. In fracture tests, self-healing composites with catalyst-free chemistry recovered as much as 82% of their original fracture toughness. The new catalyst-free chemistry has removed the barriers to cost and level of difficulty.

6.0 Biotechnological Approach of Self-Healing

One further and very interesting method of producing self-healing concrete is being developed at Delft University in The Netherlands, which makes use of mineral producing bacteria. The various types of bacteria being used are *Bacillus cohnii*, *Bacillus pasteurii*, *Bacillus lentus*, *Bacillus sphaericus* (Fig. 4) and *Pseudomonas aeruginosa*.



Fig. 4: *Bacillus sphaericus* Bacteria used for self-healing of concrete

In this system, the bacteria act as a catalyst and transform a precursor compound into a suitable filler material, such as calcium carbonate-based mineral precipitates. A microscopic view of one such bacteria treated concrete is shown in Figure 5.

The filler material then acts as a type of bio-cement, which effectively seals newly formed cracks. The bacteria approach is also being developed at Jadvpur University, Kolkata.



Fig. 5: Microscopic view of bacteria treated concrete

7.0 Conclusion

Cracks in concrete buildings, roads, and sidewalks are common and often require costly plugging. Approximately half of the ₹ 56,000 crore spent on construction work in the UK per annum is allocated to repair and maintenance of existing structures, many of which are concrete structures. As per the estimate of the Construction Industry Development Council (CIDC), New Delhi, ₹ 32,000 crore is required to rebuild India's damaged concrete structures. But if concrete could detect cracking and heal itself, then there would not only be significant cost savings, but also an environmental benefit as well since concrete production accounts for significant amount of the world's carbon dioxide emissions.

Self-healing of cracks is possible only up to certain limit. Most of these materials and technology are in research stage, which needs further studies before being applied in the practical field.

Glue From Bacteria Can 'Knit' Cracks In Concrete

[Reported from The Times of India, Mumbai Edition dated 22nd November, 2010 page 19]

London: A genetically-modified bacteria has been developed by British scientists, which can knit together cracks in concrete structures by producing a special glue. As per the research study at the Newcastle University, the microbe, can self-heal the very fine cracks to produce a mixture of calcium carbonate and bacterial glue which combine with filamentous bacteria cells to 'knit', the structure together. The bacteria used was *Bacilala Filla* to prolong the life of the structures, which are costly to build. It can also reduce the emissions of carbon dioxide as concrete production accounts for around 5% of emissions by which this can reduce environmental impact. PTI

Autogenous Healing of Engineered Cementitious Composites Under Wet-Dry Cycles

[Excerpts from the article authored by Yingzi Yang et al published in Cement and Concrete Research, Volume 39, Issue 5, May 2009, Pages 382 - 390]

1.0 Introduction

Cracks can occur during any stage of the life of a concrete structure. They can be due to the concrete material itself as in the case of restrained shrinkage, or due to external factors such as excessive loading, harsh environmental exposure, poor construction procedures, or design error. Cracks have many negative effects on the mechanical performance and durability of concrete structures. The development of concretes that can automatically regain this loss of performance is highly desirable. Along this line, self-healing of cracked concrete, commonly known as autogenous healing, is an often studied phenomenon. Experimental investigation and practical experience have demonstrated that cracks in cementitious materials have the ability to seal themselves.

The effects of various parameters on self-healing include crack width, water pressure, pH of healing water, temperature, water hardness, water chloride concentration, and concrete composition. The mechanism of autogenous healing in concrete can be different such as, further hydration of the unreacted cement, expansion of the concrete in the crack flanks (swelling of C-S-H), crystallization (calcium carbonate), closing of cracks by solid matter (impurities) in the water and closing of cracks by loose concrete particles resulting from crack spalling. Among these, the crystallization of calcium carbonate within the crack is the main mechanism for self-healing of mature concrete.

The crack width is the dominating factor for any of the above mentioned five mechanisms of self-healing to be effective. Therefore, the need of crack width control is very important for autogenous healing.

2.0 ECC an Autogenous Healing Material

Engineered Cementitious Composite (ECC) is a unique type of high-performance, fiber reinforced cementitious composite. ECC features high tensile ductility (tensile strain capacity) with moderate fiber content, typically 2% by volume. Of special interest is the capability of ECC materials to deform to high tensile strains under load, commonly over 3%, while maintaining a tight crack width of about 60 μm up to failure, as shown in Figure 1. ECC with self-controlled crack width as low as 20 μm have been developed. This steady state crack width can be seen as an inherent material property of ECC, similar to compressive strength or elastic modulus. With this characteristic, ECC material is expected to have good potential to achieve self-healing in a variety

of environmental conditions, even when the composite is tensioned to several percent strains. It appears that self-healing in ECC looks to improve the long-term ductility and durability of ECC after cracking, and establishes a much more durable civil engineering material.

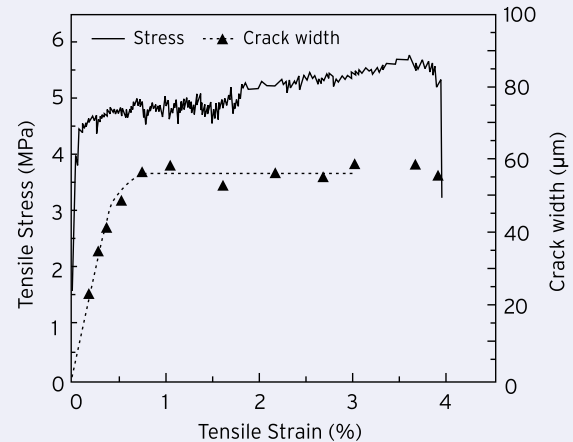


Fig. 1: Typical tensile stress-strain-crack width curve of ECC

The tight crack width in ECC is a result of its ability to experience flat crack propagation with much of the crack flank maintaining constant (steady state) crack width as the crack length increases indefinitely. Unlike normal concrete or fiber reinforced concrete, this feature of ECC allows self-control of crack width independent of steel reinforcing ratio and structural dimensions. Given this characteristic, the small crack width in specimens for laboratory investigation is identical to that in full-scale structures. When combined with the tensile strain-hardening response in ECC, desired small crack width can be easily imposed on ECC specimens for examining rehealing of crack damage, without the need for feedback control as in the case of controlling cracks in tension-softening normal concrete or fiber reinforced concrete.

While knowledge of the process of self-healing in concrete is available, specifics with regard to self-healing in ECC are limited, especially in the case of exposure to various environmental conditions. These conditions can vary greatly and include: the drying action of wind and sun; rain-water containing dissolved sulphurous compounds from industrial pollutants (i.e. acid rain); bridge-deck run-off or freezing and thawing action; sulphate attack and carbonation. This paper highlights on the self-healing of pre-damaged mature (six months of age) ECC materials under cyclic wetting and drying.

3.0 Methods of Specimens Preparation and Testing

Wetting and drying can be used as an accelerated test method to simulate outdoor environmental conditions in which ECC structures are subjected to the drying action of wind and sun and wetting by rain. Specimen damage is imposed by tension loading to fixed amount of tensile strains, which can be simulated in a laboratory test by

ponding the specimens for one day and air drying next day (CR1). This regime can be used to simulate cyclic outdoor environments such as rainy days and unclouded days. A second method of conditioning should be by ponding for one day and next day oven-drying at 55°C for 22h and air cooling thereafter (CR2). This is used to simulate cyclic outdoor environments alternating between rainy days and days with sunshine and high temperatures.

Table: 1 Mix proportions of ECC

Materials	Cement	Aggregate	Fly ash	Water	HRWR	Fiber
Unit weight (kg/m ³)	578	462	694	319	17	26

HRWR: High Range Water Reducer

The specimens were preloaded to different predetermined uniaxial tensile strain levels from 0.3% to 3%, at the age of 6 months. On unloading, a small amount of crack closure of about 15% can be observed. To account for this, all crack width measurements should be conducted in the unloaded state. Table 2 shows the average number of cracks within two pre-loaded specimen series and their corresponding crack widths over a gauge length of 100 mm. The maximum, rather than the average crack width, is reported here to highlight the extremely tight crack widths inherent in ECC as compared to concrete. While self-healing in structures will take place in the loaded state, this unloading is expected to have only a small impact on ECC self-healing capabilities. After unloading, these specimens were subsequently exposed to ten wet-dry cycles (CR1 or CR2).

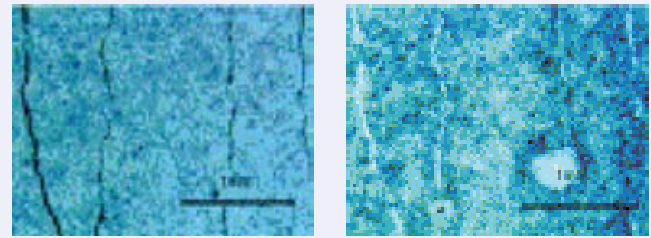
Table: 2 Crack characteristics of pre-loaded ECC

Tensile strain (%)	Number of cracks	Maximum crack widths (µm)
3	39	90
2	27	60
1	15	60
0.5	7	70
0.3	5	50

4.0 Healing Efficiency

The microstructures of ECC specimens before and after self-healing are shown in Figure 2 (a) and (b). It can be seen that abundant white residue is present along the crack lines after wet-dry conditioning cycles. It can be found out that the majority of the self-healed products are characteristic of calcium carbonate crystals.

Figure 3 shows an ECC specimen subjected to tensile loading after undergoing self-healing through the CR1 conditioning regime. This specimen was preloaded to 2% strain before being exposed to wet-dry cycles. Again, the distinctive white self-healed product can be observed in these pictures.



(a) Before self-healing (b) After self-healing
Fig. 2: Micro cracks in ECC before and after self-healing

As can be seen in Figure 4 new cracks and crack paths have been observed to form adjacent to previously self-healed cracks which now show little or no new cracking. The possibility of this event depends heavily upon the cracking properties of the matrix adjacent to the self-healing, and the quality of the self-healing material itself. However, this phenomenon serves as a testament to the real possibilities of full recovery of mechanical properties via self-healing within ECC material. Certainly, the rehealed crack shown in Figure 4 was transmitting a tensile load high enough to cause new cracking in its neighborhood.

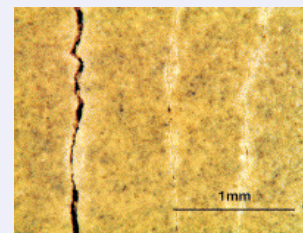


Fig. 3: Cracks through self-healed material due to reloading after wet-dry cycles



Fig. 4: Cracks through virgin ECC material adjacent to a self-healed crack held tight by self-healing material

5.0 Conclusion

The self-healing of ECC materials subject to wet-dry cycles can be used to enhance self-healing through design of cementitious materials (ECC). Also, self-healing in both transport property such as reduction in ingress of moistures, chloride ions and CO₂ etc. and mechanical properties such as strength, stiffness improves. The ECC materials should also under go some wet-dry cycles and the crack width should be limited to 150 µm and preferably 50 µm for better efficiency.

Structural Strengthening of a Multiplex During Construction Stage in Chennai - A Case Study

[Edited from the archives of the case studies of CC Division of Pidilite Industries Limited, Mumbai]

1.0 Background

The project was located at IT express highway in Chennai on Rajiv Gandhi Salai, Karapakkam near to the riverside (Fig.1). The client was constructing a mall and multiplex complex with three tier basements in an area of 5 lakhs sqft in which total built-up space was 1.25 lakhs sqft. The structure was a G+ 10 storey structure with 3 basements having total area of 18.30 lakhs sqft, mall area of 10.44 lakhs sqft, office area of 2.70 lakhs sqft and a five star hotel of 5.17 lakhs sqft. area. As the site was very near to the river, a rise in water table created enormous water pressure and caused the upliftment of the newly built raft. The raft was 450 mm thick of M40 grade of concrete (Fig. 2). The situation further worsened due to drilling of holes for releasing the upward pressure at few places on the raft. Further the client had decided to increase the number of floors from four to eleven. All these factors were responsible for repair and rehabilitation of the damaged portions as well as strengthening and increasing the load carrying capacity of raft and columns.



Fig. 1: Site location of Multiplex besides the river



Fig. 2: Raft for structural strengthening

2.0 Distress Observed

After the raft was drilled with holes to release the uplift pressure, the floor got completely flooded with water. There were structural cracks in retaining walls, RCC raft and bulging of columns of basement at many places. The structural consultant redesigned the raft foundation and advised to increase the raft size to 1200 mm from existing 450 mm of M40 grade concrete by anchoring the new concrete with old concrete with the help of bonding agent and anchor fix grouts for rebars.

3.0 Repair Materials and Methodology

The flooded area was dewatered by pumping. A sump was created outside the raft from where pumping was done continuously (Fig. 3). Raft area was dried and all the locations of cracks were identified and marked for injection grouts.



Fig. 3: De-watering by pumping

3.1 Repair of Structural Cracks of Raft and Columns with Epoxy Injection

The holes were drilled and cleaned with high pressure vacuum cleaner. Injection packers were fixed with epoxy putties for facilitating epoxy injections. The viscosity of the resin was 200 cps and pressure exerted was 8-10 bars. The injection was carried out through those installed packers with a 2-component epoxy resin. After the injection the packers were removed and holes were sealed with epoxy putties. Thus all the structural cracks in raft and columns were strengthened with a 2-component epoxy resin injection. The various properties of epoxy injection grout are given in Table. 1.

Table 1: Properties of epoxy injection grouts

Properties	Values
Viscosity	200 cps at 30°C
Specific gravity	1.02
Compressive Strength at 7 days	80 Mpa
Tensile Strength at 7 days	45 Mpa
Bond Strength at 2 days moist cure	16 Mpa
Pot life at 30°C	45 minutes

3.2 Repair of Water Leakages in Rafts and Basement with PU Injection

Certain place of the raft and wall of basement where the leakage was high, PU (Polyurethane) foam injection was used. PU resin was based on MDI (Methylene Diphenyl Isocyanate) polyurethane pre-polymer & accelerator. It had low viscosity, high penetration and very quick setting properties. It could form tough and flexible polyurethane rubber after complete chemical reaction. The various properties of two-component PU foam injection are given in Table. 2. Figure 4 shows the view of basement wall after PU injection was done.

Table 2: Properties of two-component PU injection grouts

Properties	Values
Viscosity	180 cps for a Mix 1:1
Tensile strength at 28 days	4.5 Mpa
Shear strength	0.11 Mpa
Bond strength at 2 days moist cure	2 Mpa
Relative elongation	10-20 %
Maximum expansion	40 times
Pot life at 25°C	2 hours



Fig. 4: Basement wall after PU injection

3.3 Bonding of Old and New Concrete Layer of the Raft

The surface were rubbed and cleaned thoroughly. An epoxy based bonding agent was used to bond old with new concrete of the raft. It was a 2-component with base and hardener in proportion of 1 : 0.87. It had excellent bond strength and tensile strength was higher than its bond strength. The total surface area treated with epoxy bonding agent was around 20000 sq. ft. Since the area was quite large, the bonding agent was sprayed to the surface.

To have the structural integrity, anchor fix grouts were used by anchoring 12 mm, 16 mm and 25 mm diameter rebars of embedded length of 15 times the diameter of the bar (L_a) @ 500 mm c/c through out the raft slab as shear connectors. The holes were drilled of diameter 4 mm greater than the diameter of the rebar, cleaned and

poured with modified grouts. The anchor fix grouts were polyester resin based grouts having strength more than pull out strength. Approximately 10000 numbers of holes were drilled for fixing anchor bars. The various properties of epoxy bonding agent and the anchor fix grouts are given in Table 3 and 4 respectively.

Table 3: Properties of epoxy bonding agents

Properties	Values
Specific gravity	1.02
Compressive Strength at 7 days	35 Mpa
Tensile Strength at 28 days	6 Mpa
Flexural Strength	3.5 Mpa
Shear Strength	1.4 Mpa
Bond Strength at 2 days moist cure	2 Mpa
Pot life at 30°C	5 hours

Table 4: Properties of epoxy injection grouts

Properties	Values
Specific gravity	2.0
Compressive strength at 7 days	70 MPa
Tensile strength at 7days	17.5 MPa
Flexural strength at 7days	34 MPa
Pullout strength at 7 days	30 MPa
Gell time at 30°C	20 minutes

3.4 Enlarging Sizes of Columns

The sizes of existing columns (Fig. 5) are also proposed to be increased from 1000 mm x 1000 mm to the modified design size with self-compacting concrete.



Fig. 5: Columns for strengthening

3.5 Basement Waterproofing

As the site was very close to river, the basement raft and walls were required to be waterproofed properly. The box type waterproofing system was selected for which polyester APP (Atactic Poly Propylene) torch on membrane was used. This was a heavy duty bituminous based polyester reinforced membrane of 4 mm thick. The

surface was thoroughly cleaned by a vacuum cleaner and dried. A bituminous based primer was applied over which the membrane was aligned and rolled on the surface. Thereafter it was torched on with an acetylene gas at a softening point of 115-150°C and tucked to the surface. The overlap between each successive adjacent roll was 100 mm. It could provide highly durable vapour barrier coating to the wall and raft of the basement. A screeding of cement sand mortar was provided above it for protecting the membrane from puncture or rupture at any point. The various properties of polyester APP membrane are given in Table. 5.

Table 5: Properties of APP membrane

Properties		Values
Tensile Strength in N per 5 cm width	In longitudinal direction	700
	In transverse direction	550
Elongation at Break (%)	In longitudinal direction	40
	In transverse direction	50
Tear Resistance (N)	In longitudinal direction	150
	In transverse direction	170
Resistance to water pressure		No leakage
Water absorption (%)		< 0.15

3.6 Pullout Test of Embedded Steel Bars

It was decided to do the pull out test of the 12 mm and 16mm embedded steel bars to check the proper bonding of anchor fix grouts with rebars. Results of pullout tests for design load is given in Table 6. Though the test results showed that it met the design load requirement but the client insisted to find out the failure load.

Table 6: Results of pullout tests of anchor fixed bars with grouts for design load

Diameter of the bar (d _b)	Diameter of the hole drilled for fixing the bar	Pull out test value(P) (KN)	Bond strength = $P / \pi \cdot d_b \cdot L_a$ (MPa)	Average bond strength (MPa)
16	20	51.71	4.28	4.13
		57.99	4.81	
		39.95	3.31	
12	16	43.88	6.47	4.66
		14.27	2.10	
		36.74	5.42	

L_a = Embedded length of the anchor bars (15 x d_b)

Average bond strength of embedded bars with anchor fix grouts are calculated and given in Table 6. A second pull out test was also carried out with modified sample of anchor fix grouts as per the site requirement. Results of pull out test on embedded steel bars of 12 and 16 mm diameter using anchor fix grouts and for failure load is given in Table 7. The test results were also satisfactory.

Table 7: Results of pullout tests of anchor fixed bars with grouts for failure load

Diameter of the bar	Diameter of the hole drilled for fixing the bar	Pull out test value (KN)	Remarks
16	20	36.41	Weld failure
		35.77	Weld failure
12	16	33.98	Welded bolt failure. Fracture occurred in the threaded portion of the bolt
		33.82	Weld failure

4.0 Conclusion

The site investigation of the project should be carried out thoroughly. The foundation design of the structures located near the river side area where the ground water table is high or adjacent to the catchment should be done properly. Special attention should be paid to the foundation details and design keeping in view the drainage system of the site and the upward pressure. The basement raft and walls should be properly waterproofed. The box type membrane waterproofing is the best system. Waterproofing should be done at both positive as well as negative side for such important multiplex structures. Additionally drainage system should be provided for structures which can ensure a fool proof waterproofing system. The structural strengthening of the members and waterproofing of the basement of this project was carried out successfully.

Acknowledgements

The construction chemical division of Pidilite Industries Limited expresses its sincere thanks to the executives of Client, Applicator, Mr. M. Duraisekar and Mr. Mohan Kumar of CC Division of PIL and all concerned for successful completion of this repair and rehabilitation job.

Year : 2009-2010

Client : MARG Limited, Chennai

Structural Consultant : Willways, Trivandrum

Applicator : M/S Srijai Varshini Chetech, Chennai

Repair Material Suppliers : Pidilite Industries Ltd., Mumbai

Moisture Ingress through Basement Walls Rectified with Crystalline Materials

[Excerpts from News Bulletin of ACRA (Australian Concrete Repair Association)]

1.0 Background

The walls of a basement-level archive room at a leading Victorian university in Australia were experiencing severe concrete degradation and moisture ingress due to unforeseen placement and compaction issues during initial construction. The same rectification was carried out by National Concrete Solutions, Australia.

2.0 Materials Used

Crystalline repair products were selected for reinstatement of the walls and to provide a protective barrier around steel reinforcement. Crystalline products are dry powder compounds composed of Portland cement, silica sand and many active proprietary chemicals.

Crystalline is a non-toxic, chemical treatment for the waterproofing and protection of concrete. Its primary and most distinguishing performance feature is its unique ability to generate a non-soluble crystalline formation deep within the pores and capillary tracts of the concrete. A crystalline structure permanently seals the concrete against the penetration of water and other liquids from any direction.

3.0 Methodology Adopted

Preparation for the basement wall involved the removal of existing paint and other contaminants from areas that were damaged from water ingress. Additionally, all deteriorated concrete areas were pressure-washed to provide an open capillary, clean absorbent surface, and bony and honeycombed sections were chipped out to a square-edged substrate and surface laitance was removed. The surfaces were prepared for application of crystalline coating as shown in Figure 1.



Fig. 1: Surface prepared for application of crystalline coating

Upon successful completion of surface preparation, the substrate was saturated with water and crystalline

was applied as a slurry coat to treat the exposed steel and reinstate a passive alkaline barrier around the reinforcement. A high-build repair mortar for the patching and resurfacing of deteriorated concrete was then used to repair back to contour with the surrounding concrete.

Crystalline coating was uniformly applied to all concrete surfaces with a semi-stiff bristle brush. It produced a harder finish, providing enhanced concrete durability and additional waterproofing integrity.

A dense, fully-developed crystalline structure had formed within the capillary tracts of the concrete to completely block the flow of water after application of crystalline at a depth of 50 mm into the concrete sample at 28 days (Fig. 2).



Fig. 2: Crystallization being formed for blocking capillaries

A curing compound of self-dissipating (2 - 3 days) non-film forming product was applied as a fine mist spray, both, during and after the coating to accelerate the crystalline process and assist in product curing for optimum performance.

4.0 Conclusion

The crystalline coating is most suitable for preventing moisture ingress of structures such as reservoirs, sewage and water treatment plants, underground vaults, secondary containment structures, foundations, tunnels and subway systems, swimming pools, parking structures and roof decks, etc.

The various tests such as permeability, chemical resistance, compressive strength, freeze thaw and other tests have all indicated positive results after using the crystalline product. It can also be used on all structures containing potable water.

It can also be used on negative sides. Crystalline is also well-suited for crack repair in water-retaining structures. These chemicals lie dormant until a new crack forms. Water entering through the crack reactivates the chemicals and causes new crystals to form and grow, which self-seal the new cracks and maintain a watertight seal for which it is a permanent crack repair solution. This self-sealing property is one of most unique and useful features and can often reduce long-term maintenance and repair costs.

Programmes Conducted

• In-house Training Programmes

Tackle cracks in structures - A holistic approach

Date : 8th Oct 2010

Attendees: M.N. Dastur & Co. Pvt. Ltd., Acute Arcch Consultants, Mumbai Port Trust, Riddhi Enterprise, Noble Protective System, Colours Civil Care (Civil Contractor & Waterproofing Contractor), Painterior (I), MCGM (Municipal Corpn Greater Mumbai), Edifice Erection Pvt. Ltd & private contractors.



Structural Diagnosis and Condition Analysis of RC Structures

Date : 9th - 10th Dec 2010

Attendees :

Indian Oil Corporation LTD., Leak Proof Water Proofing, Navika Waterproofing, Sunvich Technologies, Hindustan Petroleum Corp. Ltd., Gateway Terminals India Pvt. Ltd., VR Ruksham Projections Colours, DAKSH, Tata Consulting Engg. Ltd., Kamala Raheja Vidyanidhi Institute for Architecture and Environmental Studies.



• National Level Joint Training Programmes

Advancements in Construction Chemicals

Date : 20th Nov 2010

Jointly with : Indian Concrete Institute (ICI), Pune

Venue : ICI, Prabhat Road, Pune

Build - Your Structure Waterproof

Date : 26th Nov 2010

Jointly with : Sahyadri Engineering Academy

Venue : Sahyadri Engineering Academy, Pune

• Knowledge Awareness Sessions

"Tackle Leakage in RC Buildings"

Venue : State Bank of India CBD Belapur, Navi Mumbai

Date : 26th Oct 2010

Venue : Institution of Engineers, CBD Belapur,
Navi Mumbai

Date : 12th Nov 2010

• Expert Meet on Heritage Conservation

An expert meet on heritage conservation was organised by the Institute at Pidilite industries Ltd., Mumbai on 19th November, 2010 on most appropriate being first day of "World Heritage Week". The leading Conservation Architects, Conservation Engineers, Restoration Contractors, Art Conservators, Representatives of Mumbai Metropolitan Region-Heritage Conservation Society and Chhatrapati Shivaji, Museum, Mumbai, Professors of Architecture Colleges from different parts of the country participated in this meet. The interactive session focused on the development compatible materials, shortage of trained man power, need for uniform standards and specifications, and further improvement in education and training for conservation of heritage structures. In the action plan, two priority areas such as (i) materials and testing and (ii) education were selected. To spearhead their activities, two committees were formed for creating a common platform and to carry forward the conservation works in a more scientific manner.



Training Programmes and Seminars

Forthcoming Training Programmes

DFI-SPR has scheduled the following training programmes for the upgradation of knowledge base of Practising Engineers, Waterproofing and Repair Contractors, Consultants, Architects, Faculties and Students from Engineering Colleges.

Sr. No.	Date	Venue	Topic	Fees	Details of the topic
1	12th & 13th May 2011	DFI-SPR, Andheri (E), Mumbai	Build your structure Waterproof	₹ 3000	<ul style="list-style-type: none">• Cause and Need of Waterproofing of Structures• Building Envelope - A Design Consideration• Waterproofing of Roofs and Terraces• Waterproofing of Internal Wet Areas• Basement Waterproofing• Waterproofing of Walls
2	15th July 2011	DFI-SPR, Andheri (E), Mumbai	Protection Measures against Weathering Distress in Concrete Structures	₹ 1500	<ul style="list-style-type: none">• Manifestation of Weathering Distresses• Protection Measures against Reinforcement Corrosion• Protective Coating for Concrete against Chemical Resistance• Waterproofing Coating Systems
3	29th & 30th Sept 2011	DFI-SPR, Andheri (E), Mumbai	Structural Diagnosis and Repair of Concrete Structures	₹ 3000	<ul style="list-style-type: none">• Distresses in RC Structures• Condition Survey• Diagnostic Techniques• Methods of Non Destructive Tests• Damage Rating

Corporate Training Programme

In addition to the above scheduled programmes, we do organize separate corporate training programmes on specific topics as per the needs of the customer.

Distance Education Programme for Practising Engineers

One year Graduate Programme is being offered by DFI-SPR jointly with NICMAR, Pune for practising Engineers on subjects of:

- Waterproofing and Repair Management of Concrete Structures

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International Journal of 3R's

(Repair, Restoration and Renewal of Built Environment)

ISSN 0975-8968



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