TECH TALK

SMART CONCRETE

A real 'smart' material integrates information technology with structural engineering followed by actuation and locomotion. Can self-healing concrete be a 'smart' material? **DR ANJAN K CHATTERJEE, Director, Dr Fixit Institute of Structural Protection & Rehabilitation,** gives us the answer.

It is important to note that the IT age has not left the engineering materials 'dumb'. Dumb materials and structures contrast sharply with the natural world where the animals and plants have the clear ability to adopt 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 manmade 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 minimise 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.

'Sensual' structures

There are many possibilities for such materials and structures in the manmade 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)'.

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 emphasises only 'Sensual' function. Smart materials and structure not only 'sense' but also 'adapt' to their environment.

A durable cementitious material reduces carbon dioxide emissions.

Healing properties

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 researches are expanding the horizon of smart concrete as, apart from carbon fibres, carbon black, steel slag, nanophase materials, etc can also be added to provide better ability of concrete 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. The inspiration of self-healing comes from biological systems, which have the ability to heal after being wounded.

Initiation of cracks and other types of damages on a microscopic level has been shown to change thermal, electrical, and acoustical 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.

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.

The real process

The natural self-healing ability of concrete, known as autogenous healing whose 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 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. The various factors which affect the amount and rate of autogenic healing are 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.

Methods of healing

The simplest way of self-healing 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. There have been a number of healing agents used which are liquid-based or in a solid-state. But the most common healing agents being used are epoxy resins, polyurethanes, cyanoacrylates, and alkali-silica solutions.

Self-healing properties are 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 in crack repair. The other method of self-healing is introducing healing agents in glass or ceramic tubes dispersed through the concrete matrix. Cracks form in the concrete matrix wherever damage occurs and subsequently these cracks break the glass tubes, releasing the healing agent and catalyst into the crack plane through capillary action. When both components come in contact, the polymerisation reaction is triggered (Fig.1) and the crack faces are bond together.

Fig.1a PU healing agent before polymerisation

Fig.1b PU healing agent after polymerisation

(Source: Nele De Belie, Magnel Laboratory for Concrete Research, Ghent University, Belgium)

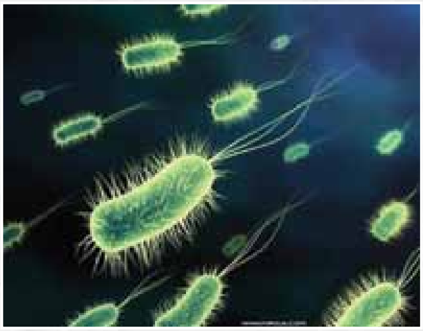

Fig. 2 Bacillus sphaericus used for self-healing of concrete

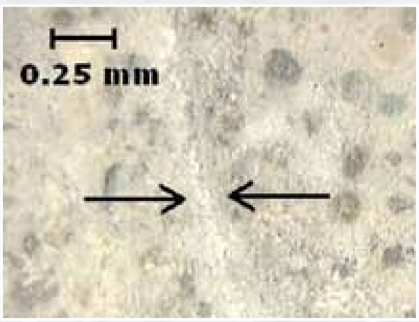

Fig. 3 Crack repaired with bacteria in Sol-gel medium

(Source: Nele De Belie, Magnel Laboratory for Concrete Research, Ghent University, Belgium)

An embedded material of polymeric or ceramic in concrete can lower production costs.

The various types of mineral producing bacteria being used for self-healing are Bacillus cohnii, Bacillus pasteurii, Bacillus lentus, Bacillus sphaericus (Fig. 2), and Pseudomonas aeruginosa. 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. The filler material then acts as a type of bio-cement which effectively seals newly formed cracks. To protect the bacteria from higher alkalinity of the concrete the carrier materials generally used in tubes are PU (Polyurethane) and SG (Silica Gel). One such crack repaired with bacteria in sol-gel medium is shown in Fig. 3.

Sodium silicate is being used as inorganic self-healing material to produce a calcium-silica-hydrate gel which not only self-heal but also act as a corrosion inhibitor. Additionally, the gel deposits on the surface of the concrete, making a protective coating.

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.

Concrete benefits

An embedded material of polymeric, ceramics, etc in concrete 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. A more durable cementitious material will allow less maintenance and a longer working life, reducing the amount of cement required and reducing the world's carbon dioxide emissions thus reducing the environmental and economic impact. CBT

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 this objective.

Dr Chatterjee, Director, Dr Fixit Institute of Structural Protection and Rehabilitation, c/o Pidilite Industries Ltd, Mumbai, had a long tenure with ACC Ltd and was its Wholetime Executive Director. Prior to joining ACC, he was GM with the then Cement Research Institute of India (now National Council of Cement and Building Materials). He is a Materials Scientist with professional experience of over four decades. He runs a consultancy firm Conmat Technologies Pvt Ltd, Kolkata, which offers services in the fields of cement, concrete and other construction materials.