Autogenous Healing

CPAA

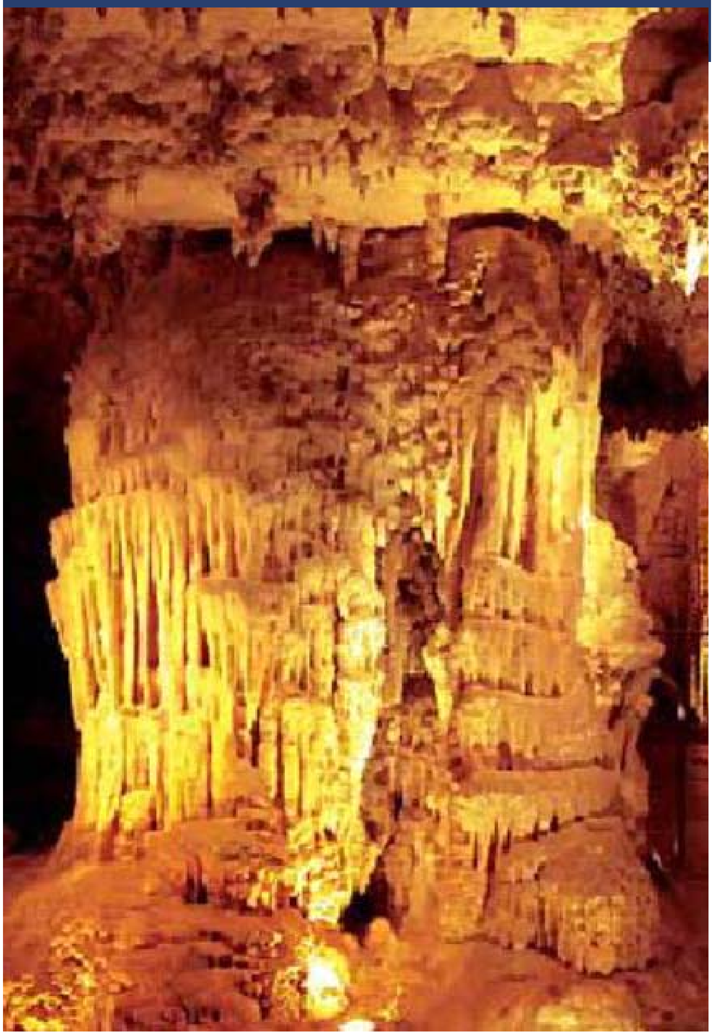
Concrete Pipe Association of Australasia

Technical Brief

Autogenous healing

Concrete properties such as strength, durability, versatility and economy are well known to engineers, designers, inspectors and contractors. These qualities are enhanced due to the type of mixes used in concrete pipes. However, one of the most important properties of concrete, and in particular, concrete pipe, is often overlooked. This property is the process of **autogenous healing!**

Long before the advent of portland cement or concrete pipes, water containing dissolved carbon dioxide was percolating through calcareous rock, dissolving calcium and transporting it in solution to locations where it might again be deposited as solid calcium carbonate. The fantastic structures found in limestone caves are formed in this way. In this process carbon dioxide assists initially with dissolving the limestone – the more carbon dioxide in the water, the more calcium it can dissolve. Solid calcium carbonate is deposited if some of the carbon dioxide in the water escapes into the atmosphere or evaporation increases the concentration of dissolved calcium.



The internal architecture of limestone caves is created by a process similar to autogenous healing

Mechanism of autogenous healing

Autogenous healing is the ability of concrete to repair or heal cracks in the presence of moisture. For a brittle material, subject to dimensional changes depending on the amount of moisture present, the self-healing property of concrete is crucial to its application in water-retaining structures.

Water passing through concrete dissolves small amounts of calcium from the cement. While the cement paste in dense, high strength concrete as used in pipes, is to all intents and purposes impermeable to water, thin-walled concrete structures will often contain discontinuities which allow water to pass through. These may be cracks which have arisen in either the plastic or hardened state, internal separation at surfaces of reinforcing wire or coarse aggregate, or local porous areas. It has been found that, given favourable conditions, calcium originating from the cement will be deposited in insoluble form in the void spaces and eventually seal them. The process is particularly relevant to concrete pipe because the service conditions often provide an ideal environment for autogenous healing to take place.

Autogenous healing was recognised at an early stage of the development of concrete structures, and it was noted further that cracks were not only visibly healed, but strength was also restored. Reported by Abrams in 1913[1] , a 12 m reinforced concrete bridge was loaded at three months age, producing diagonal tension cracks. After three years of exposure to the weather, the cracks were healed. Later testing to a much higher load produced new cracks but did not re-open the ones which had previously healed. In another report by the American Concrete Pipe Association, following a load test on an unreinforced concrete pipe[2], the pipe was cracked but remained intact, and was put aside. Tested in the same orientation three years later, the pipe withstood an even greater load than in the original test.

Autogenous healing at an advanced stage on a water retaining concrete structure

Autogenous healing in concrete pipes

Autogenous healing is common in buried reinforced concrete pipe due to the presence of moisture, either on the soil side or inside the pipe itself. These non-moving cracks, when healed autogenously, are impermeable and can yield a structure stronger than the original. One of the reasons is that the concrete pipe seals the crack with calcium-carbonate crystals formed when the carbon dioxide in the surrounding soil, air and water carbonates the free calcium oxide in the cement and the calcium hydroxide liberated by the hydration of the tricalcium silicate of the cement. The formula for this reaction is:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_20$$

The white line signifies internal autogenous healing in this concrete pipe

Necessary conditions for autogenous healing

In a recent review, Adam Neville[3] summarises literature having a bearing on conditions necessary for autogenous healing of cracks. At an early age, continuing cement hydration in which calcium silicates in the cement are converted to calcium silicate hydrate can play a direct role in the healing process. In cracks healed at a later stage in the life of a structure, the main product which fills the crack is calcium carbonate, formed by combination of calcium from the hydrated cement with carbon dioxide dissolved in water from the atmosphere or other sources. Neither water hardness nor pH has been found to influence the process of autogenous healing. Various investigators have reported different maximum widths at which cracks have healed – "not surprising because the test conditions have varied widely. In some cases, the cracks were caused by shrinkage, in others by the application of tension, usually flexural but in some tests by direct tension. The age at the opening of cracks varied too. The healing took place in static water or flowing water. There was a head of water or not. The water was fresh or seawater."
Among examples reported are reinforced concrete pipes that developed shrinkage cracks up to 1.5 mm wide, and were subsequently put into service. Five years later, the cracks were found to be completely closed by autogenous healing.

Hydrated cement is partly soluble in water[4], whether or not there is carbon dioxide present. Carbon dioxide dissolved in low concentration from the atmosphere plays a role in the healing process, precipitating calcium carbonate, but is not necessary to initially dissolve calcium from the cement. Autogenous healing will take place unabated in concrete made with blended cement, even though such concrete may be found not to contain any "free lime". Roberts[5] confirms that the type of water and the cementitious material have minimal effect.

The Role of Autogenous Healing in Corrosion Prevention

For reinforcing steel to corrode, moisture must be present both for its part in the chemical reaction at cathodic sites on the steel surface, and to provide a conducting path through the concrete for the electrolytic current. If the concrete is cracked, the same moisture provides a condition for autogenous healing. Initially, the environment at the root of a crack may be favourable to steel corrosion, particularly if the water contains chloride which breaks down the passive film on the steel. Some rust will be formed, occupying a larger volume than the original steel and perhaps tending to disrupt the surrounding concrete. However given an ability on the part of the concrete to resist such disruption, autogenous healing will progressively restore a situation in which the corrosion is unable to continue. Calcium hydroxide, silicates and carbonate will be deposited in the crack, on the surface of the steel and in the pores of he rust. Of the two competing tendencies – disruption by rust, or isolation of the steel surface, assisted by autogenous healing, circumstances will allow one or the other to predominate.

Continued on next page.

The white line signifies autogenous healing on this exposed concrete pipe

The Role of Autogenous Healing in Corrosion Prevention continued

A number of investigations have been concerned with cracked concrete exposed to a marine environment. In a series reported by Beeby[6], tests were carried out using beams loaded to give crack widths of up to 0.4 mm. The beams were broken open after 1, 2, 4 & 10 years. At the earlier ages (1 and 2 years) the extent of corrosion was less in the finer cracks but after ten years the remaining difference was small; ie at this time a change had taken place which effectively neutralised the influence of the original crack width. The review by Neville[3] deals at length with the related issues of cracking and durability, reporting a conclusion from the work of Vennesland and Gjorv[7] that precipitation of reaction products may effectively clog cracks and thereby inhibit corrosion before there has been any damage to the steel. A later investigation concerned more specifically with autogenous healing in a marine environment[8] found that cracks of width less than or equal to 0.5 mm healed before there was any significant effect on the reinforcing steel. It concludes that autogenous healing can play a leading role in achieving sustainable marine concrete structures.

There is no suggestion that the salt in a marine environment contributes to the actual process of autogenous healing. Its effectiveness in the face of such a powerful driving force for corrosion underlines the ability of autogenous healing to prevent corrosion damage of reinforcing steel at cracks, under both mild and severe conditions of service.

A concrete miracle?

After initially suggesting this description through the title of his review, Neville is forced to conclude that autogenous healing is not a miracle after all and prefers instead the biblical reference, "Physician, heal thyself". In the presence of moisture the cement in a concrete structure continues to hydrate, enhancing the strength and durability of the concrete. Autogenous healing is an extension of this life-like quality.

References

1. D A Abrams, "Tests of a 40 ft Reinforced Concrete Highway Bridge",ASTM Proceedings 13, 1913, p 884.
2. Concrete Pipe Handbook, American Concrete Pipe Association, 1998, pp 6-18, 6-19, reporting a test carried out 1928-1931.
3. A M Neville, "Autogenous Healing – a Concrete Miracle?", Concrete International, November 2002, pp 76-82.
4. J J Chen, J J Thomas, H F W Taylor, H M Jennings, "Solubility & Structure of Calcium Silicate Hydrate", Cement & Concrete Research 34, 2004, pp 1499-1519.
5. D Roberts, "Autogenous Healing – the Self Healing of Fine Cracks", Concrete Advice No. 09, The Concrete Society, July 2003.
6. A W Beeby, "Corrosion of Reinforcing Steel in Concrete and its Relation to Cracking", The Structural Engineer 56A, No. 3, March 1978, pp 77-81.
7. O Vennesland, O Gjorv, "Effect of Cracks in Submerged Concrete Sea Structures on Steel Corrosion", Corrosion '81, Toronto, Ontario, August 1981, pp 49-51.
8. T U Mohammed, H Hamada, H Yokuta, "Autogenous Healing: Ingress of Chloride & Sulfate through Cracks in Concrete Under Marine Environment", Seventh CANMET/ACI International Conference on Recent Advances in Concrete Technology, 2004, pp 135-154.