Basilisk
self healing concrete

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Autogenous healing of concrete

The water tightness of a concrete structure is for a big part dependent on the occurring of cracks. Due to the presence of cracks, water can easily seep through the structure and cause leakage nuisance. However, concrete is known for having self-healing properties in the field of preventing leakage. When designing a concrete structure for wet environments, engineers usually depend on the self-healing capability of concrete for the calculation of crack managing steel reinforcement. Yet, time after time practice shows that very often self-healing fails with leakage as a result, especially since the last decennia. But why is this? Why can't we rely on the passive self-healing capacity of concrete and what can active autonomous healing do about this?

Let's start with the mechanisms which provide passive self-healing in concrete. Self-healing in concrete is known to be caused by four processes which can occur simultaneously, but also may serve as water tightening on their own. The techniques are the following:

- A) The formation of calcium carbonate (limestone)
- B) Loose particles blocking the crack path
- C) Ongoing hydration of unbound cement particles in the crack
- D) Swelling of the cement matrix

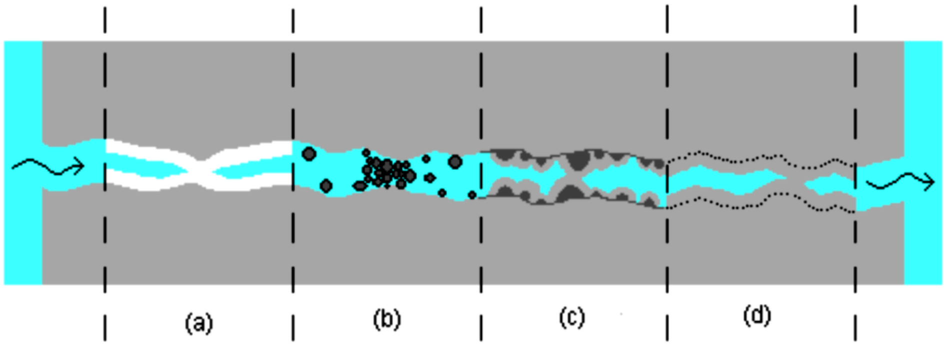

Figure 1, Mechanisms for self-healing (after [1])

Even though these processes seem quite self-evident, it seems to be not sufficient to fully assume water tightness. After all, for self-healing to be able to occur by (one or more of) these mechanisms, it has to meet some important conditions, and so has limitations [2].

First, the crack has to be stable. These are typically cracks that are crossed by steel reinforcement and are considered dormant. Unstable cracks are usually working joints, and will mostly occur around pour breaks. Secondly, penetrating liquid should not be aggressive nor have leaching properties. And at last, the flow rate in the crack should not be too large, thus the crack width shall not be too big.

Provided that the above mentioned conditions are met, autogenous healing may occur for crack widths up to 0.2 mm, according to Lohmeyer's table, see fig 2.

This table shows the relation between critical crack width w_{crit} and ratio of liquid head and wall thickness. The graph is based on practical observations and is accompanied by the results of two other researchers Meischner and Schiessl. But for engineers the values of Lohmeyer have the preference for practical applications, most probably because it is on the most safe side. The extremes (limits) of this table are also included in the European standard EN 1992 – 3 section 7.3.1 and even allows to linearly interpolate between 0.05 and 0.2 mm and is therefore less strict than Lohmeyer.

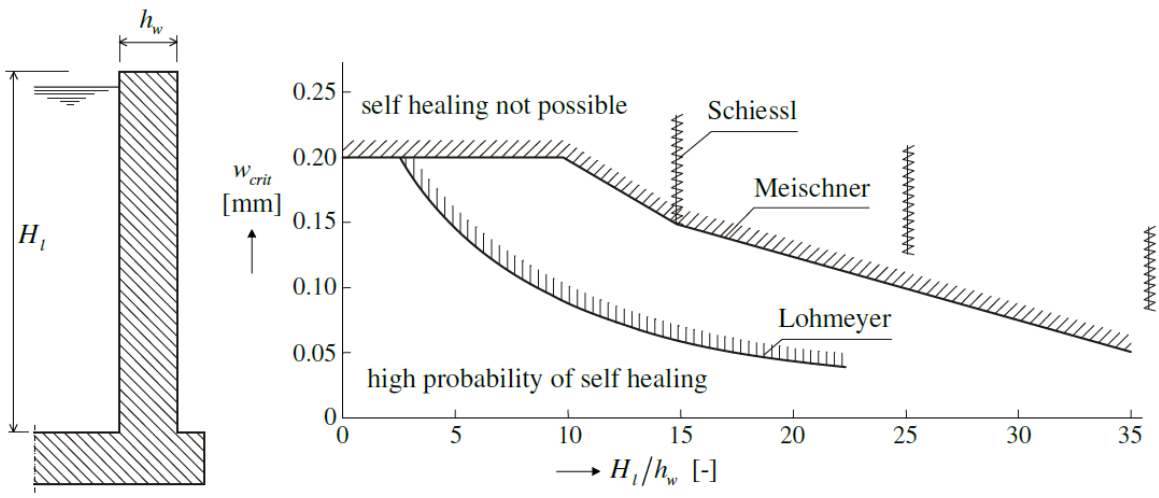

Figure 2 Lohmeyer's table (after [3])

But why do we still see leakage in practice? Well, the earlier mentioned four mechanisms may either be outdated or perhaps overestimated. Down below the explanation why this can be the case.

Formation of calcium carbonate

The cement in concrete consist of several products, including calcium hydroxide ($Ca(OH)_2$). This calcium hydroxide can react with carbon dioxide (CO_2) present in the air in the crack or in the penetrating water and form calcium carbonate ($CaCO_3$), also known as limestone. But it so happens that calcium hydroxide easily dissolves in water. As a result, a part of the calcium hydroxide available on the surface of the cracks will dissolve in the penetrating water and wash out of the crack during leakage. Because of the highly presence of CO_2 in the outside air, the calcium hydroxide will react only at this point with CO_2 and form limestone (calcium carbonate). Therefore, the lime will precipitate on the outer surface around the crack, rather than form inside the crack. In the pictures below, the results of limestone formation in regular concrete is compared to concrete with active self-healing capabilities, thus concrete with Healing Agent.

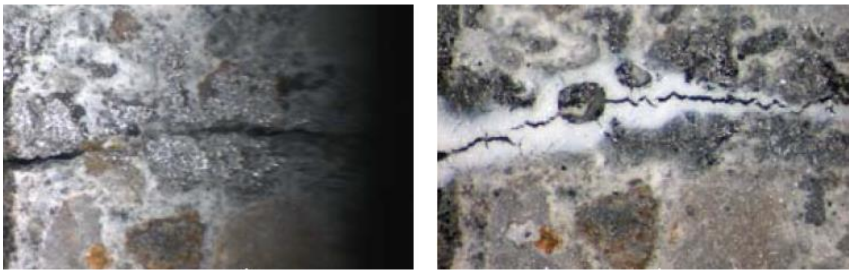

Figure 3 Control concrete before and after healing. Precipitation of lime on the surface around the crack is clearly visible

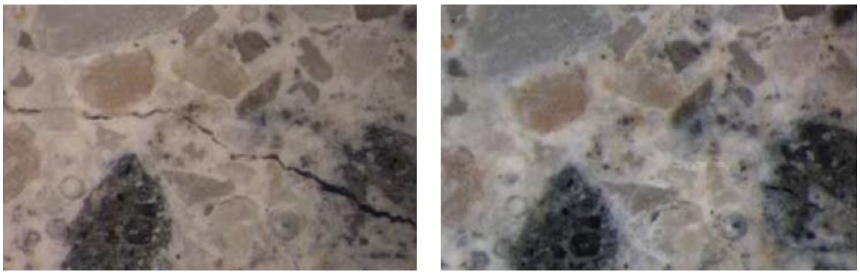

Figure 4 Concrete with Healing Agent before and after healing. The inside of the crack is clearly filled.

Loose particles blocking the crack path

For loose particles to be able to block the flow path in a crack, we have to speak of quite young concrete [4]. This may be unbounded cement particles which can occur in only young concrete or other loose material. In fact, it is a very weak mechanism to rely on and just assume for loose particles to clump together and block the path. Also with higher flow rates, the chances are small for these particles to hold on in the crack.

Ongoing hydration

Researches in the past have shown that the capacity of autogenous healing depends on the amount of Portland cement clinker and in particular the size of the cement particles. The coarser the cement, the bigger the self-healing capacity of the concrete [5][6][7]. If a crack occurs *through* a big sized particle, then as a result the unbounded part of this particle (the inside where the crack hits the particle) will react with the penetrating water and will hydrate, with cement stone as an end product. This will further tighten the crack till there is no more water available. This is the case when the crack is sealed through this phenomenon. However, big cement particles are in contrast to the developments through the last decades in the field of mixture compositions for low CO_2 profiles and fast strength developments. This development may be the reason why we see less self-healing.

High amounts of CO_2 emission during the production of cement is a common discussion in the cement industry. Worldwide, cement producers are put under pressure by the government to lower the CO_2 profile of their cement. But a low CO_2 profile and fast strength development, demands binders with low clinker content and fine grind. The replacement of clinker with ground granulated blast-furnace slag or with fly ash may lead to less capability of self-healing. Fine grind will no longer provide unreacted cement in a later stadium, because small particles will be fully hydrated. Besides, continuation of the hydration process, caused by un-hydrated cement particles, is believed not to happen. The reason for this is because the distance between the two crack faces is generally too large to be bridged by hydration products [8].

Moreover, to manage crack formation in watertight structures, usually the cement composition will already be preferred with less clinker to lower hydration heat which will minimize cracks. And as mentioned above, less clinker may lead to less self-healing capability. However, in this type of cement compositions, crack sealing may be expected in (only) younger concrete. The slower development of cement may lead to healing caused by ongoing hydration of remaining unreacted cement provided that there is water available in the crack. But again, only the case in younger concrete before it reaches the ultimate strength.

Swelling of the cement matrix

Swelling may occur when the concrete is exposed to an environment with high relative humidity. The cement stone will absorb water and this will cause the stone to expand. But the healing capacity caused by swelling is actually very low and depends very much on the environment. Studies have shown that healing caused by swelling in the cement matrix lies between 0,005 mm to 0,01 mm [9]. Adding swelling materials to the matrix may lead to increase of the healing capacity. After all, they are capable of absorbing huge amounts of water and this will lead to swelling. Because of the absorbing property, in a later stadium they can also be used as internal water source in concrete for healing mechanisms. Still, the healing capacity of swelling materials in concrete is moderate and may be expected up to 0,025 mm [9]. As a matter of fact, swelling in concrete may cause even more cracks as well because of internal expanding [9] due to e.g. delayed ettringite formation [10][11]. Also, adding certain components makes it no longer subject to autogenous healing.

In summary

Eventually, relying on the very limited self-healing capacities of concrete and having huge expectations may cause disappointments in practice because of above mentioned reasons. The healing mechanism of the micro-organisms in Basilisk Healing Agent is the formation of limestone. This is actually increasing the natural self-healing capacity of concrete. Adding Healing Agent, thus giving active self-healing capacities will add extra assurance and enables to accept wider crack widths while retaining a watertight structure!

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