

# Study and Analysis of Structural Cracks and Rectifying by Innovative Method

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**ABSTRACT:**Cracking is one of the major challenge faced by Civil Engineer is to carry out suitable repairs and remedial measures for cracks. For repairs and remedies to be effective, it is essential that the engineer should have proper understanding of various causes of cracking. For investigating the causes it is necessary to observe carefully location, shape, size, depth, behaviour and other characteristics of the cracks, and to collect information about specifications of the job, time of construction and past history of the structure. It will also be necessary for the engineer to know as to when the cracks first came to notice and whether the cracks are structural or non-structural. Structural cracks are those which are due to incorrect design, faulty construction, poor workmanship, Poor Quality & Material, overloading and these may endanger the safety of a building. Non-structural cracks which are due to moisture changes, thermal variations, elastic deformation, creep, chemical reaction, foundation movement and settlement of soil, vegetation, etc. Non-structural cracks are mostly due to internally induced stresses in building materials and these generally do not directly result in structural weakening. In course of time however, sometimes these cracks may, because of penetration of moisture through cracks or weathering action, result in corrosion of reinforcement and thus may render the structure unsafe. Therefore a study was conducted on cracks and repairing by bacteria based healing was investigated.

**KEYWORDS:**Self-healing, bacteria-based, cracks repair,

## I. INTRODUCTION

Modern structures are comparatively tall and slender, have thin walls, are designed for higher stresses and are built at a fast pace. These structures are, therefore, more crack-prone as compared with old structures which used to be low, had thick walls, were lightly stressed and were built at a slow pace. Moreover, moisture from rain can easily reach the inside and spoil the finish of a modern building which has thin walls. Thus measures for control of cracks in buildings have assumed much greater importance on account of the present trends in construction [1]. Crack formation in concrete is a phenomenon that can hardly be complete avoided due to for example shrinkage reactions of setting concrete and tensile stresses occurring in set structures. While larger cracks can potentially hamper structures integrity and therefore to require repair actions, smaller cracks typically with a crack width smaller than 0.2 mm are generally considered unproblematic. Although such micro cracks do not affect strength properties of structures they do on the other hand contribute to material porosity and permeability. Ingress of aggressive chemicals such as chlorides, sulphates and acids may result on the longer term in concrete matrix degradation and premature corrosion of the embedded steel reinforcement and thus hamper the structures durability on the long term. In several studies indications have been found that concrete structures have a certain capacity for autonomous healing of such micro cracks [2 -4]. The actual capacity of micro crack healing appears primarily related to the composition of the concrete mixtures. Particularly mixtures based on a high binder content show remarkable crack-healing properties what is due to delayed (secondary) hydration of matrix embedded non hydrated cement and binder particles upon reaction with crack ingress water. Autogenous self-healing of cracks in traditional but also high-binder content mixtures appear limited to cracks with a width smaller than 0.2 mm. This somewhat limited effectiveness appears largely due to the restricted expansive potential of the small non-hydrated cement particles lying exposed at the crack surface. Another limitation to application of highbinder content mixtures solely for the purpose of increasing self-healing capacities are current policies which advocate sparse use of cement in concrete for sustainability reasons as current cement production contributes about 7% to global

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anthropogenic CO<sub>2</sub> emissions. For latter reasons, alternative and more sustainable self-healing mechanisms are therefore wanted. One possible mechanism is currently being investigated and developed in several laboratories, i.e. a technique based on the application of mineral-producing bacteria. Hence in this study, an experiment was conducted to repair the cracks (0.2mm) using a particular bacterial species.

## II. BACTERIA USED

Spore-forming alkali-resistant bacteria were isolated from sediment originating from a natural soda lake (strain C2-C2-1A) as well as obtained from the German Collection of Microorganisms and Cell Cultures (DSMZ), Braunschweig, Germany (strain *Bacillus pseudofirmus* DSM 8715). To induce copious spore formation both strains were cultivated in an alkaline medium containing 20 mM sodium citrate as energy and carbon source for growth. The medium was further composed of 0.2 g NH<sub>4</sub>Cl, 0.02 g KH<sub>2</sub>PO<sub>4</sub>, 0.225 g CaCl<sub>2</sub>, 0.2 g KCl, 0.2 g MgCl<sub>2</sub>·6H<sub>2</sub>O, 0.375 g KNO<sub>3</sub>, 50 mM NaHCO<sub>3</sub>, 50 mM Na<sub>2</sub>CO<sub>3</sub>, 1 ml trace elements solution SL12B and 0.1 g yeast extract per litre Milli-Q ultra-pure water. Before addition to cement mixture for test specimen preparation, bacteria were cleaned from culture residues by repeated centrifugation and re-suspension of obtained cell pellet in clean tap water.

## III. BIO-MINERAL PRECURSOR COMPOUNDS AND SAMPLE PREPARATION

Three different organic compounds, peptone, calcium lactate and calcium glutamate, which could be used by both bacterial strains as energy and carbon sources for grows, were tested for their potential applicability as bio-mineral precursor compound in concrete. Cement stone specimen (4 × 4 × 4 cm) were prepared by mixing ordinary Portland cement with tap water using a water/cement weight ratio of 0.4. Series without further additions served as controls while to the other series organic compounds in a quantity of 1% of cement weight were added to the cement paste mixture. In addition, bacterial cement stone specimen was prepared by mixing tap water washed.

## IV. HEALING

Cell suspensions with cement in a similar water/cement weight ratio. Before mixing the number of bacteria in used cell suspensions were quantified by microscopic analysis, and number of bacteria in resulting specimen amounted to  $5.8 \times 10^8$  cm<sup>-3</sup> cement stone. Series of 6 specimens each were tested for compressive strength after 3, 7 and 28 days curing to investigate possible negative effects of healing agent additions to strength development. To investigate bio-mineral producing potential of applied healing agents, test specimen comprising one healing agent component (bacteria only; strain C2-C2-1 A), both healing agent components (bacteria plus calcium lactate) and no healing agents (controls) were prepared. Concentration of healing agents in cement stone specimen was identical to specimen used for compressive strength testing. After 7 and 28 days curing, specimen were broken and further incubated in demineralized water, basic medium, or in basic medium amended with 20 mM sodium glutamate plus 6 g/L yeast extract. Basic medium was similar to bacterial growth medium, except that this medium lacked carbonate buffer and organic compound additions. After 10 days incubation at room temperature, specimen fragments were rinsed with demineralized water and without any further preparation directly studied for mineral formation at crack surfaces by environmental scanning electron microscopy (Philips ESEM XL30 Series) equipped with an X-ray microanalysis (EDAX) system 3.

## V. EFFECT OF HEALING AGENT ADDITIONS ON SPECIMEN STRENGTH

As incorporation of healing agents to concrete may have unwanted negative effects on material properties, development of compressive strength of control specimen without additions as well as specimen with bacteria or organic compound additions was investigated. Incorporation of a high number of bacteria ( $5.8 \times 10^8$  cm<sup>-3</sup> cement stone) appeared to have a mildly negative effect on compressive strength development as bacterial test specimen appeared almost 10% weaker than control specimen at all tested times (Figure 1A). Effect of organic compound incorporation on development of strength appeared however strongly dependent on compound identity. Incorporation of peptone resulted in a catastrophic development as initial strength (after 3 and 7 days curing) was already less than 50% of the control, prolonged curing resulted in an even lower compressive strength. Strength development of calcium glutamate containing specimen appeared, like the bacterial specimen, parallel to control specimen albeit at a 25% lower level

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(Figure 1C). Additions of calcium lactate did not significantly affect strength development as values were only slightly lower or higher than control specimen.



### VI. MINERAL FORMATION ON SPECIMEN CRACK SURFACE

Cement stone specimen with and without (control) incorporated bacteria were tested for their mineral-producing capacity. Specimen with only incorporated bacteria but incubated in sodium glutamate plus yeast extract amended medium appeared to produce copious amounts of precipitates which formed plate-like aggregates on specimen crack surfaces. Although on crack surfaces of control specimen (not comprising bacteria) also whitish precipitates could be observed, these were less pronounced, did not form plates, and moreover were characterized by a lower Ca/C ratio as determined by X-ray analysis. This indicates that latter precipitates were rich in organic carbon and possibly represented precipitated glutamate and/or yeast extract derived organic compounds. In contrast, the plate-like precipitates appeared enriched in calcium carbonate ( $\text{CaCO}_3$ ) as Ca/C ratio of these were closer to major element composition of a control specimen.

### VII. BACTERIAL REACTION TO REMEDIATE CRACKS

When the concrete is mixed with bacteria (*Bacillus subtilis*), the bacteria go into a dormant state, a lot like seeds. All the bacteria need is exposure to the air to activate their functions. Any cracks that should occur provide the necessary exposure. When the cracks form, bacteria very close proximity to the crack, starts precipitating calcite crystals. When a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria start to feed on the

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calcium lactate nutrient. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. Oxygen is an essential element in the process of corrosion of steel and when the bacterial activity has consumed it all it increases the durability of steel reinforced concrete constructions. Bacteria embedded concrete has lower water and chloride permeability and higher strength regain than the surface application of bacteria. Key component of the self-healing concrete formula is the bacteria themselves. The most promising bacteria to use for self-healing purposes are alkaliphilic (alkali-resistant) spore-forming bacteria. The bacteria, from the genus *Bacillus*, *subtilis* is adopted for present study. It is of great concern to the construction industry whether or not these bacteria are “smart” enough to know when their task is complete because of safety concerns. *Bacillus Subtilis* which is a soil bacterium (isolated from JNTUH soil) is harmless to humans as it is non-pathogenic microorganism.

## VIII. DISCUSSION

Self-healing concrete should be able to heal or seal, by filler material formation, freshly formed cracks to inhibit ingress of water and other chemicals which could cause preliminary degradation of the material matrix or embedded reinforcement. In this study we investigated the bio-mineral production capacity of cement stone specimen in which bacteria were incorporated as healing agent. The integrated bacteria applied in this study are affiliated to alkali-resistant spore-forming species of the genus *Bacillus*. Bacteria of this group, and particularly their thick-walled spores, were previously shown to be able to survive cement stone incorporation. However, bacteria represent only one part of a needed two-component healing system, as for autogenous healing also mineral-, or filler, precursor compounds need to be incorporated in the material matrix. Here we have obtained evidence that at least one such a component, calcium lactate, as well as high numbers of bacteria, can be included in the material matrix without significantly compromising material compressive strength properties. Other tested organic compounds in this study, peptone and calcium glutamate, appeared much less suitable for incorporation as this, compared to control samples, resulted in an unacceptable decrease in strength development. In practice, an integrated two component healing system such as bacteria plus calcium lactate may not always be needed. Particularly concrete in wet environments such as marine or subsurface structures may be exposed to present bacteria and/or organic compounds dissolved in ingress water. However, as environmental conditions vary widely, types of locally present bacteria and organic compounds may not result in formation of crack-filling products, but instead exert a negative influence on the concrete matrix or embedded steel reinforcement.

Particularly acid-producing bacteria such as sulphur ammonium-oxidizing strains are likely harmful as their metabolic waste products etch and dissolve the concrete matrix. For this reason anti-microbial chemical agents are sometimes purposely added to concrete mixtures to inhibit bacterial activity. However, results from this and previous studies indicate that bacteria can also exert positive influences. Bacteria and mineral precursor compounds applied externally, thus as surface treatment or repair system have been shown to effectively seal surface cracks [11] [12]. This shows that bacterial influences on concrete structures do not always have to be necessarily negative. To act as a fully self-healing mechanisms, however, both bacteria and filler precursor compounds need to be integrated in the material matrix. Incorporating high numbers of appropriate bacteria and filler material precursor compounds in the material already during construction lowers the risk of possible negative effects of harmful bacteria intruding the concrete matrix with ingress water at a later stage. As this practice seems straightforward for the incorporation of spore-forming bacteria it appears from this study that this may not apply for mineral precursor compounds. Here we have shown that incorporated bacteria can produce copious amounts of calcium carbonate-enriched precipitates from sodium glutamate present in ingress water. However, substantially less mineral production was observed when both healing components, bacteria and calcium lactate, were incorporated. A reason for this phenomenon may be that calcium lactate added to the cement paste mixture may have become completely integrated in the material matrix and thus not accessible for bacterial conversion later on. Apparently only a minor amount of incorporated calcium lactate was present in the matrix capillary pore system resulting in only insignificant mineral formation. A potential solution to this problem could be encapsulation of the healing agent before addition to the cement paste mixture, a mechanism analogous to what was proposed for self-healing in polymer composites. This would ensure the presence of a substantial reservoir in the material matrix containing original chemical healing agent which is also accessible for bacterial metabolic conversion. The conclusion of this study is that a bacteria-based self-healing system in concrete appears promising. However,

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before a functional two component system needed for truly autogenous healing can be applied, further technical developments are project we have shown the proof-of-principle, i.e. that concrete-incorporated bacteria can produce copious amounts of minerals which can potentially seal freshly formed cracks. The crack-sealing capacity and concomitant reduced material permeability will be quantified in our on-going research project.

## IX. CONCLUSION

From the above study it is concluded that Microbial technology has proved to be better than many conventional technologies because of its eco- friendly nature, self-healing abilities and increase in durability of various building materials. The other methods repairing cracks increase the crack width later due to the presence of moisture in freshly laid concrete. Thus this method of crack repairing reduces the possibility of further cracking. Work of various researchers has improved our understanding on the possibilities and limitations of biotechnological applications on building materials. Enhancement of compressive strength, reduction in permeability, water absorption, and reinforced corrosion has been seen in various cementitious and stone materials. Cementation by this method is very easy and convenient for usage. This will soon provide the basis for high quality structures that will be cost effective and environmentally safe but, more work is required to improve the feasibility of this technology from both an economical and practical viewpoints.

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