AUTONOMOUS PROCESSES IN CONCRETE MATRIX ON BIO PRODUCTS

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Received: May 17, 2021
Accepted for publication: June 28, 2021

Abstract. In this paper are presented different approaches of microbiological type, on the concrete matrix, that has the ability to self-healing the micro-cracks in their early phase. Although the prevention of cracks in the concrete structure is not possible, there are many types of techniques that will lead to self-sealing. Thereby we can say the cracks represent the biggest enemy of the elements in the constructions, and if they are not observed and treated in the early phase, they can create real dangers, both for the constructions and for the people. The micro-cracks appeared in the concrete matrix are determined by a number of internal and / or external factors. The determination of the cause of the appearance of the micro-cracks is done by visual inspections and by direct measurements, using special equipment. The identification of the various biological compounds and their use in autonomous processes can represent a sustainable but also efficient alternative on the costs of concrete production. From the researchers’ reports, the application of chemicals and polymers represents a source of risks for human health, plus the fact that these methods are viable in the short term.

The bio products exemplified in this paper are found in nature, are human friendly, and through the information provided by the researchers we can say that they increase the life of the construction. An important feature of the use of organic products in the concrete matrix is the fact that the concrete can self-healing, only

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needing water and oxygen. The two approaches of autonomous type presented in this paper are similar in terms of the result obtained but different from the point of view of the healing agents used. This paper will provide an overview of the bio approach through the production of calcium carbonate, will present the new challenges for sealing the micro-cracks and recommendations for future research.

**Keywords:** sealing; concrete; bacteria; cracks; self-healing.

1. **Introduction**

From the beginning, researchers have tried, experimented and tested various bio products that, added to the concrete matrix, resulted in a self-sealing process, thus eliminating the intervention on degraded elements for different reasons, through consolidations and rehabilitations. More precisely the elimination of the human factor of intervention and extension of the life of the construction. Concrete is considered to be a composite material composed of water, aggregates, cements, additives (plasticizing additives, plug modifier additives and hardener additives, waterproofing additives, dyes or waterproofing additives). It is widely used in the construction of buildings, storage tanks, dams, ports, roads, bridges, various other infrastructures, being one of the materials that are part of human life. Concrete as a building material is considered to be degradable over time, his mass cracking and micro fissuring being considered inevitable. The cracks represent the effective path for the aggressive agents (salts, carbon dioxide, acids, etc.) with repercussions in time on the durability of the material and implicitly of the whole construction. The cracks can be produced by external causes (loads, deformations imposed) and generated inside the concrete (concrete contraction, temperature variations, repeated frost-defrost action, corrosion products, plastic concrete filling, irregularities in the execution process). The French academic environment in 1836 explained that the cementitious materials have a real potential in the self-healing capacity - self-sealing of the micro-fissures through the phenomenon of conversion of calcium hydroxide resulting from the hydration of the cement into calcium carbonate by exposure to the usual atmospheric conditions (Mihashi, 2012). There are two methods of self-healing, namely:

1) Autogenous healing represents the intrinsic property of the material to heal itself, without human help. An example would be the so-called Roman mortar based on volcanic ash and lime which by its self-sealing capacity ensures longevity of ancient structures over 2000 years (Fig.1).
In 2005, Weterbeek (Ghosh, 2013) states that calcium in consistent deposits dissolves in the presence of water precipitating into cracks, ensuring their partial closure and preventing their evolution, thus implicitly ensuring the longevity of old bridges in Amsterdam, Utrecht or Delft (Fig. 2).

2) Self-healing involves the additives designed to be mixed in a concrete matrix for healing purposes and also uses special techniques to transport such additives (Amir S., et. al, 2019). This process uses the integration into the structure of the material of two components: the healing agent (bacterium) and the catalyst (the reaction initiating agent). The two components can be introduced into the material
through 3 systems: microcapsules, capillary tubes and a microvascular system.

Starting from the idea that the cracks represent the gateway of the liquid and the harmful gases into the concrete matrix and its slow but safe bringing to an irremediable degradation, we can say that there is an urgent need to intervene with new elements in the matrix structure even from the phase of conception. It must be taken into account that these bio-composites are not harmful to humans and the environment. In this paper, the biological approach is a suitable alternative for self-sealing of the micro-cracks.

2. SELF-HEALING IN THE CONCRETE MATRIX WITH BIO COMPONENTS

2.1. SELF-HEALING WITH THE HELP OF BACTERIA

Autogenous healing upon contact with water is based on three processes: swelling of the cement matrix, hydration of non-hydrated cement particles and precipitation of calcium carbonate. The most significant process is the precipitation of calcium carbonate (CaCO₃), which is formed as a result of the reaction between carbon dioxide (CO₂) and calcium hydroxide (Ca(OH)₂).

$$\text{CO}_2 + \text{Ca(OH)}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$$  \hspace{1cm} (1)

The occurrence of precipitation depends on the amount of calcium hydroxide present and the solubility product of calcium carbonate, which in turn depends on temperature, ionic strength, composition, pH and partial carbon dioxide and water pressure in the crack (Jia L., et al., 2018). First, the amount of precipitation and, therefore, the healing potential of cracks depends on the amount of calcium and carbonate ions available in the cracks. It is known that microorganisms, especially bacteria, can produce a wide range of minerals such as carbonates, sulfides, silicates and phosphates (Fortin et al., 1997). Calcium carbonate is one of the most suitable fillers for concrete, due to its high compatibility with cement compositions. Calcium carbonate can be precipitated (Fig.3), by the process of biologically induced mineralization in the presence of a calcium source. In this process, carbonate is produced by extracellular microorganisms through two metabolic pathways, namely: autotrophs and heterotrophs. To reach self-healing, researchers in Delft, the Netherlands, have identified a bacterium that feeds on calcium lactate by precipitating calcium carbonate. The bacterium belongs to the Bacillus class, lives in strongly alkaline
environments such as: alkaline lakes in Kulunda (Siberia, Russia), Playa (Aragon, Spain) and Wadi Natrun (Egypt).

Concrete can heal itself, just like the human body. Henk M. Jonkers, one of the researchers, says the bacterium can stay dormant in the concrete for about 200 years, and becomes instantly active, under the influence of humidity, (Emily M., 2015). From those reported by the researcher, the bacterium needs water and oxygen to activate. In (Fig. 4) shows the mechanism of action and closure of the cracks using bacteria (Bacillus).

The bio-concrete created by dutch researchers also bears the name of self-healing concrete or bacterial concrete. It is specially designed to increase the life span of concrete structures with the help of self-healing action. The organic concrete differs from the other concrete by the presence of two important components, namely:
• bacteria, which must withstand the alkalinity and the efforts made in the concrete (most of the bacteria of the Bacillus class that meet the criteria of the organic concrete are: pseudofirmus, cohnii, filella, pasteruri);

• the chemical precursor that activates the bacterium (the precursor = is a chemical compound that participates in a chemical reaction), the most suitable being calcium lactate (Chirag B., et al., 2017).

The two components are encapsulated LWA (Fig.5) (light weight aggregates), (R. Alghamri et al., 2016), the impregnation of the capsules is done under vacuum with the solution of calcium lactate, yeast extract and bacterial spores’ solution. Immediately after completion of the impregnation, they are dried for 5-6 days at (20 ± 2°) temperature with (60 ± 10%) RH up to a constant weight; (E. Tziviloglou, et al., 2015). The capsules thus obtained are used in the preparation of fresh concrete. Also, another method of using healing agents is by injecting or spraying the existing concrete elements, introducing the healing agent as deep as possible.

![Fig.5 - LWA capsule](http://www.liapor.com/en/products/raw-material.html)

Bacterial concrete has the following advantages and disadvantages:

1. Advantages

- helps to fill the cracks (sealing them);
- improving the compressibility of the concrete;
- the oxygen that leads to corrosion of the metal elements is
consumed by bacteria;
- better frost resistance;
- reduces the impermeability of the concrete;
- reduces the corrosion in the reinforcement of the concrete;
- helps to reduce maintenance and repairs.

2. Disadvantages

- the cost of organic concrete is almost double compared to conventional concrete;
- the growth of the mentioned bacteria is not possible in any environment;
- all studies on calcite precipitation investigation are expensive;
- if the volume of bio products (bacteria and calcium lactate) exceeds 20% then decreases the strength of the concrete;
- skilled labor force is needed.

This new technology can provide new development directions for roads and sustainable hydrotechnical constructions with a higher load capacity (Chirag B., et al., 2017). As a conclusion, organic concretes are more friendly to nature and their ability to self-heal increases the durability of different building materials and offers them a much greater resistance to conventional materials, thus leading to an increase in the lifetime of buildings, (Chirag B., et al., 2017).

2.2. BIO SELF-HEALING WITH FUNGAL SPORES

Another organic product that help to seal the micro-fissures is the use of fungal spores of fungi (Trichoderma reesei) together with nutrients, for the production of calcium carbonate. This method has the advantages of microorganism’s survival in extreme environments, at extreme temperatures, high salinity, high pressure, high radiation, intense ultraviolet light and variable acidity (R. Chávez, et al., 2015), as opposed to bacteria, which do not survive in harsh conditions (J. Luo, et. To, 2018). The type of fungi that can be used for self-healing of the concrete are alkali mushrooms, respectively, filamentous fungi. Unlike bacteria, when they are deprived of the nutrient, they produce latent and highly resistant cells called spores, which can survive in an inactive state for long periods of time, waiting for favorable conditions. For example, in 2004, spores from a fungus that lived about 400,000 years ago germinated in a laboratory in India (Hamilton, G. 2006).

The growth of filamentous fungi occurs in the form of tubules resembling individual nucleus strings and cell walls, which are interconnected and therefore form a complex three-dimensional network called mycelium (F. Baluska, et al., 2006). It has been observed that such a filamentous mushroom colony has a high surface / volume ratio (Menon et al., 2017). Also, the fungal cell wall has a substance called chitin (N-acetyl-glucosamine) (Roncero, 2002), which is a long
carbohydrate polymer that forms a substrate and prevents the growth of fungi but favors the attraction of mineral ions on their cell walls, thus forming mineral deposits (G.M. Gadd, 1993). Similarly, to bacteria, fungi need nutrients, and during the occurrence of cracks, water and oxygen penetrating through the cementitious materials help the spores to germinate and grow and therefore, clogging of the cracks is obtained (J. Luo, et al., 2018). The use of fungi can be considered a safe method, being non-pathogenic, without causing infections in humans and animals.

3. CONCLUSIONS

From the specialized literature studied, regarding the two autonomous methods presented in this article, the phenomenon of self-healing involves a combination of complex chemical and physical processes. Most of the time the healing occurs due to the reactions of the non-hydrated particles already existing in the cement matrix, the newly formed hydration products being able to ensure a partial filling of the volume of cracks. Bio-self-healing in the concrete matrix is limited by the encapsulation of the healing agents. Bio-self-healing, whether autonomous or autogenous, must meet a number of sustainable conditions and various protocols before applying on an industrial scale. Both technologies presented in this article regarding the sealing of micro-cracks in concrete, using bacteria or fungi, lead to the same result, namely the precipitation of calcium carbonate. The major problem is how to apply the bio components in the freshly prepared concrete matrix, as they must withstand contact with water and oxygen, avoiding their activation at this stage.

The current policy is to reduce the amount of cement needed in a concrete mix, as its production is environmentally friendly due to high energy consumption and CO\textsubscript{2} emissions. Starting from the obligation to permanently create materials with low impact of CO\textsubscript{2} emissions, current and future research must investigate possible harmful effects on the environment and human health before using healing agents for cement-based materials. The researches in the field will have to analyze the connection between filling products and the edges of the crack, the way of clogging large cracks, the reduction of associated costs (with reference to the costs of bacteria, nutrients and labor), as well as the sustainability of the solutions. It is worth mentioning that the development of this new research direction, the accumulation of knowledge and implicit experience in the field of advanced bio composite materials, especially the introduction of self-healing systems, will respond to the identified needs for increasing the level of sustainability of the constructions.
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PROCESE AUTONOME IN MATRICEA BETONULUI PE BAZA DE PRODUSE BIO

(Rezumat)

În acest articol sunt prezentate diferite abordări de tip microbiologic, asupra matricei betonului care are capacitatea de a autovindeca microfisurile din faza incipientă a acestora. Deși prevenirea formării unei fisuri nu este posibilă, există destule tipuri de tehnici care să ducă la autosigilare. Putem spune că fisurile reprezintă cel mai mare dușman al elementelor din construcții, iar dacă nu sunt observate și tratate din timp acestea pot genera reale pericole, atât pentru construcții cât și pentru oameni. Microfisurile apărute în matricea betonului sunt determinate de o serie de factori interni și/sau externi. Determinarea cauzei apariției microfisurilor se face prin inspecții vizuale și prin măsurări directe, folosind aparatură specială. Identificarea diverselor compuși biologici și utilizarea acestora în procese de tip autonom poate reprezenta o alternativă sustenabilă dar și eficientă asupra costurilor de producție a betoanelor. Din raporturile cercetătorilor aplicarea substanțelor chimice și a polimerilor reprezintă o sursă de riscuri pentru sănătatea umană, plus faptul că aceste metode sunt viabile pe termen scurt. Produsele bio exemplificate în acest articol se regăsesc în natură, sunt prietenoase cu omul, iar prin informațiile oferite de cercetători putem spune că ele cresc durata de viață a construcției. O caracteristică importantă a utilizării produselor bio în matricea betonului este reprezentată de faptul că betoanele se pot autovindeca, fiind nevoie doar de apă și oxigen. Cele două abordări de tip autonom prezentate în această lucrare sunt asemănătoare din punct de vedere a rezultatului obținut dar diferite din punct de vedere al agenților vindecători folosiți. Prin acest articol se va oferi o imagine de ansamblu asupra abordării bio prin producerea de carbonat de calciu, se vor prezenta provocările noi în vederea sigilării microfisurilor și recomandări pentru viitoarele cercetări.