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Advantages and disadvantages of the use of self-repairing concrete in Colombia

Ventajas y desventajas del uso del concreto autorreparable en Colombia

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Concrete is one of the most widely used building materials in the world. It is economical, fire-resistant, and malleable, which allows it to adapt to a wide variety of constructions. For this reason, techniques and processes are being sought every day to improve this material so that someday it will not require any type of maintenance and will have a long useful life. Self-repairing concrete or bio-concrete is a material created in the 21st century that can seal the cracks in it, thanks to the fact that it contains certain types of bacteria that allow closing those openings. An investigation is carried out on the impact that the application of self-repairing concrete in Colombia would have in the different fields of construction, using the favorable and unfavorable characteristics that this concrete has, and the results that have been obtained with its use in other countries.

Keywords: Bacteria, Colombia, concrete, research, self-repair

El concreto es uno de los materiales de construcción más utilizado alrededor del mundo. Es económico, resistente al fuego y maleable, lo que le permite adaptarse a gran variedad de construcciones. Por ello, día a día se buscan técnicas y procesos que perfeccionen dicho material de manera que algún día no sea necesario realizarle algún tipo de mantenimiento y tenga una vida útil amplia. El concreto autorreparable o bio-concreto es un material creado en el siglo XXI que tiene la capacidad de sellar las gritas que en él hayan, gracias a que contiene cierto tipo de bacterias que permiten cerrar esas aberturas. Se realiza una investigación sobre el impacto que tendría la aplicación del hormigón autorreparable en Colombia en los distintos campos de la construcción, por medio de las características favorables y desfavorables que tiene este concreto, y los resultados que se han obtenido con su uso en otros países.

Palabras clave: Autorreparación, bacterias, Colombia, concreto, investigación

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Introduction

Concrete is a material used in construction that is a product of a mixture of sand, gravel, and water that is used for the elaboration of various structures such as aqueducts, bridges, and buildings, as it has various properties such as great strength, resistance, and durability that make it one of the fundamental materials for the creation of quality constructions (Beltrán et al., 2013; Kianimehr et al., 2019; Li et al., 2019).

Over the years, the structures of antiquity and the possible materials used in them have been studied, since a large number of them are preserved in good condition despite the hundreds of years they have and the natural phenomena they have had to suffer, and as a result, it has been discovered that concrete is one of those materials that make them up (El-Anwar, 2018; Eryshev, 2019; Menon et al., 2019). However, the conditions and characteristics of factors such as weather and climate have drawn the most attention and, as a result, are the most studied, as they are an important part of the process of improving current concrete and researching and developing different types of it for various conditions that occur on planet Earth.

A team of Dutch scientists from Delft University of Technology, led by microbiologists Henk Jonkers and Eric Schlangen, developed a type of concrete that can self-repair or self-heal due to a component of the mixture that is bacteria with the ability to generate calcium lactate, which can seal cracks and crevices (Morsali et al., 2019; Vijay & Murmu, 2019; Xu et al., 2019).

This innovative material has had a great impact in different parts of the world, so research was conducted to describe the advantages and disadvantages of the application of bio concrete in Colombia because this is a country that needs constructions and buildings made with quality materials since in recent years it has had to see how new and old works that had different purposes and characteristics, collapsed not only because of bad procedures or poor workmanship but because of wear (in the case of the old ones) and because the materials used in them were not appropriate for the terrain, conditions, and ecosystems of the country (Kua et al., 2019; Müller et al., 2019).

A material for the future

Conceptualization

To begin determining which factors make self-repairing concrete a topic of study worth perfecting, it is necessary to understand what processes lead to its creation and which materials compose it; for this, it is critical to define basic concepts that allow understanding the characteristics of this material in a technical and basic manner (Caicedo et al., 2019).

First of all, the idea of self-repairing concrete arose from the need to make concrete in structures more durable and stable, together with the need to reduce costs in the long term in today's different constructions. Concrete has been one of the most versatile materials on the market, and because of this, it has become the most widely used material today, so much so that what we now call metropolises are known, in colloquial terms, as concrete jungles.

To know the importance of this material, it is essential to recognize that this branch of science marked the beginning of an era, which has been different from any other, for its innovation in research and application of lasting technologies. Its birth took place in one of the most important civilizations in evolution, which was responsible for giving humanity treasures such as arches, aqueducts, and well-known cities. The Roman civilization has had a great influence on the research that engineers have developed today, this is because their constructions have managed to overcome barriers such as time and the many adversities they have had to face. These structural gifts that they left hundreds of years ago, are made of a material that has been an element of research for several decades and is known as *opus caementicium*, also called Roman concrete.

Today, concrete does not have the same resistance as the one used for buildings such as the Roman Coliseum and the Temple of Concord, which is still standing after hundreds of years. This situation generated confusion among researchers for many decades, as they could not explain how it was possible that a material discovered hundreds of years ago could surpass today's technological advances. After many years, they finally found an answer to the reason why the type of concrete implemented by the Romans has been so durable and special. been so durable and special. This discovery has brought with it a particular conclusion: the reaction of volcanic rock with salty seawater created a rare mineral called *tobermorite aluminum*.

Self-repairing concrete

The researchers assure that the prolonged exposure of this mineral to saltwater caused a propagation in the concrete fabric, which together with a mineral called *phillipsite*, grew over time, reinforcing the concrete and preventing the appearance of cracks (Mors & Jonkers, 2020). This finding was the trigger that prompted the research of new methods to implement a similar material in buildings since it is not possible to implement a constant application of saltwater in buildings to reinforce the structures to prevent cracking (Fig. 1).

This is the basis of bio-concrete, which is a type of concrete that can self-repair or self-heal, sealing the cracks that form over time and deterioration due to exposure to hostile environmental factors (Beglarigale et al., 2019). self-healing, sealing cracks that form with the passage

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Figure 1

Bioconcrete, self-repairing concrete (Arq, 2020).

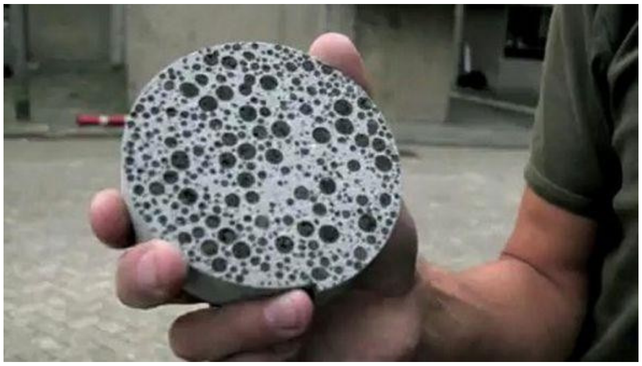

Figure 2

Dutch professor creates concrete that repairs itself (Editores, 2020).

of time and deterioration due to exposure to hostile environmental factors.

Bio-concrete began as an experiment at the Technical University of Delft, located in the Netherlands, led by concrete expert Eric Schlangen and microbiologist Henk Jonkers, who developed a revolutionary and innovative material to solve the aforementioned imperfection (Fig. 2).

The solution consists of adding a bacterium called *Bacillus pseudofirmus*, which can last several centuries, as long as it does not come into contact with oxygen. This bacterium consumes some of the aggregates of concrete, which are cement, water, and aggregates, including calcium lactate, the latter is the food that allows the bacteria after its digestion the production of limestone, which upon contact with the humidity of the air increases its dimensions sealing cracks in three weeks (Hong et al., 2019).

Although the process may sound incredible, it has certain limitations that affect its applicability, since its effectiveness is not compromised when the cracking occurs along the length, but if, on the contrary, it occurs with a thickness of more than 0.8 centimeters, this process becomes ineffective.

It is called bio concrete, because the application of organic material, such as bacteria, in construction allows it to be recognized as a biological material since it is alive, which allows the wear and tear of buildings to regenerate. In this sense, buildings and other constructions behave like living beings since they can heal their wounds. That is, strengthen their structure to compensate for the damage caused by wear and tear.

Its use has been tested in countries such as Ecuador, to build irrigation canals, as this is a highly seismic country (Al-Tabbaa et al., 2019). Latin America has been the primary target for the application of this technology due to several factors, including its location in what is known as the Pacific Ring of Fire, which stretches from the coasts of Asia to America and contains the world's highest seismic and volcanic activity. Countries where this belt crosses include Chile, Argentina, Bolivia, Peru, Ecuador, Colombia, Central America, Mexico, and the United States.

One of the most recent investigations of this material has been carried out at the University of Colorado, which proposes a concrete with the same purpose as the Delft researchers, but with a new addition to the mixture, the hydrogel, whose function is to retain water and nutrients to provide a favorable environment for cyanobacteria. This process can be compared to other processes observed in nature, such as the crab that loses a pincer or the lizard that loses its tail, and after a while, they regenerate.

One of the outcomes of the research conducted at the University of Colorado was the creation of a brick made of sand, hydrogel, and bacteria within two hours, after which more quantities of the mentioned materials and nutrients were added, resulting in two bricks after six hours, indicating that the bacteria had done their job.

One of the crucial factors, according to a study conducted on the impact of self-repairing concrete on the road structure, is temperature, as this influences the regeneration period, the cracks did not seal at 4 degrees Celsius, while at 35 degrees Celsius, there was much less sealing than at 23 degrees Celsius. The effect of the bacteria is observed at 23 degrees Celsius because the control specimens did not yield positive results, whereas the specimens with the self-repair agent yielded sealed cracks of up to 0.3 mm (Gonzalez et al., 2018).

Advantages and disadvantages of self-repairing concrete

Concrete fracturing and repair methods

Since the beginning of the use of concrete as a construction material in the main Colombian cities, multiple problems have been encountered as a result of fracturing

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caused by weather and environmental factors. For this reason, research has been carried out in different countries to find a solution to one of the problems, which, as mentioned above, is the fracturing of concrete due to environmental damage, which has caused many structures, already deteriorated, to cause collateral damage in sectors adjacent to their construction.

Concrete is the preferred material used in the construction of buildings worldwide. Large cities or metropolises, as they are also known, are concrete jungles, since all that can be observed is one construction after another, built with different types of concrete treatments, such as reinforced concrete, prestressed concrete, prestressed, post-tensioned, prestressed bonded, or unbonded, interior and exterior prestressing.

The reinforcement in reinforced concrete is an integral part of the section and bears the tensions that the concrete cannot. Steel is a force in prestressed concrete before it is reinforcement. It is load-independent, and if sufficient, the beam behaves elastically under the loads considered. Cracking, in particular, is eliminated without limiting the stresses in the steel, as they developed before the application of the loads. The prestressing steel can, under certain circumstances, function as reinforcement. The treatment that the reinforced concrete receives is the same treatment that the bio concrete receives, that is to say, that the procedures to achieve the expected reinforcement in the concrete, will continue being the same, but, they will have a vital difference, which is the addition of bacteria, that in contact with the humidity of the air, will carry out the process of self-repair of the concrete.

Fractures in concrete can be superficial, of a certain depth, and could even compromise the integrity of the structure, the reasons for this type of situation vary in nature and complexity, among which are: deterioration due to marine conditions, exposure to chemical reactions, affectation by natural phenomena, earthquakes, floods, fires, damage resulting from weathering, erosion, humidity, impacts, wear, displacement or fracture generated by thermal stresses, settlement, shrinkage, overloads, structural deficiencies caused by miscalculation of loads, corrosion of the elements, as well as errors in design and detailing, architectural failures generated by poor construction, the use of inadequate materials and significant neglect associated with supervision and quality control. These situations that generate fracture damage in concrete highlight the importance of generating effective repair methods that act on time.

The methods for the repair of cracks in concrete, taking into account the nature of the affectation, the reform or restoration that can be cosmetic (superficial) or could require the replacement of all or part of the structure, broadly speaking are: the use of epoxy resins, cements grouts, mortars and the use of polymer concrete composites, however, these methods suggest additional expenses in studies and repair materials, which make that if the repair is not carried out in adequate periods, the damage increases and the probability of loss of the structure also increases.

The main characteristic of bio concrete is the structural repair of damages smaller than 0.8 mm wide, in contact with the humidity of the environment and temperatures higher than 4°C, this type of repair could prevent major damages, which would drastically reduce the costs of evaluation and repair materials in a significant way. Especially in Colombia, because the humidity in the environment is quite high, which allows the work developed by the bacteria to be much more effective and better. In addition to the bacteria, the bio concrete contains traditional concrete and calcium lactate, which serves as food for the bacilli for them to produce limestone, a material that regenerates cracks. It is also better than traditional concrete because it doesn't set up too quickly, as it's exposed to air for longer.

The bacteria and calcium lactate in the mixture are in biodegradable plastic capsules that, when cracks appear in the structures, come into contact with water and open, allowing the bacteria to multiply and feed before secreting the limestone that will repair the existing cracks over three weeks. Without the bacteria and calcium lactate, materials expand when wet.

According to research conducted at the Technical University of Delft, the use of this living concrete represents economic savings because there will no longer be a need to repair the structures, as they can do it themselves. In this way, the era of biological constructions will be lived.

Bio concrete background

To provide an adequate value of importance to bio concrete, it is necessary to know what have been the characteristics and results obtained by researchers regarding the benefits brought by the application of this innovative biological technology. The main benefit offered by the application of bio concrete in constructions and buildings at present is self-regeneration, but it is not the only one, it also offers greater resistance to compression, reduction of permeability, among others.

However, the main topic of this article is the benefits offered by self-healing concrete through bacterial encapsulation. The cost of maintaining concrete structures in the United States alone is estimated to be $20 million per year. This statement highlights one of the greatest advantages in the application of bio concrete and that is the budgetary savings offered by bio concrete. The most important factors for promoting the reparative behavior of bacteria are air and humidity. When the crack comes into contact with the environment, bacteria feed on the calcium lactate produced and convert it to calcite, resulting in the crack sealing. This type of bacteria can go dormant for up to

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200 years and reactivate only when necessary (Ponce et al., 2015).

In addition to the self-repair of concrete as a benefit, there is added resistance to situations such as compression. The addition of *Bacillus subtilis* increased the compressive strength of concrete by 14.92 percent, while Bacillus Sphaericus increased the compressive strength of concrete by 30.76 percent at 3 days, 46-15 percent at 7 days, and 32-21 percent at 28 days when compared to conventional concrete.

Mitigating the formation of micro-cracks has become more important than one might think because as a result of these, major damage can form in the structure once the concrete has hardened and is in service. If micro-cracks form in the concrete and water is present, the sleeping bacteria or sporula becomes active. The bacteria, using the calcium source of its food calcium lactate, will act as a nucleation center to precipitate calcium carbonate (CaCO3), which will totally or partially seal the cracks (Guzmán & Ramírez, 2017). Based on this characteristic, it can be affirmed that the creation of cracks that put a structure at risk begins to diminish from the very moment the microcracks are formed, preventing damage that increases with the prolongation of time.

Bacteria are not permanently active, but certain characteristics must be met for them to fulfill their function, once they begin their work, they need food to survive and produce the calcium carbonate that will precipitate in the cracks, that is why to fulfill this function a specific process is fulfilled. To protect the bacteria from crushing and the hostile environment of concrete, they are encapsulated in a porous aggregate, expanded clay. The expanded clay (4-75-1.18 mm) is impregnated with the bacteria solution (12 percent of the clay's weight), yeast extract (5g/l of bacteria solution), and a calcium source, in this case, calcium lactate (200g/l of bacteria solution).

Different variables have been determined that allow demonstrating the importance of research in the application of bacteria in the concrete mix, to create a biological construction material that allows increasing the resistance of the structures and the time that they last, as well as decreasing notoriously the maintenance costs caused by micro-cracking caused by environmental or natural factors. It is important to point out that in developing countries this technology would provide new opportunities in the development of road infrastructure and construction in urban sectors, both in the main cities and in small towns that are in the process of development, since the decrease in maintenance costs allows a small town to improve the quality of its constructions, without worrying about the expense that would represent a study for preventive maintenance, or even a study for an internal repair, adding to this the materials for the concrete repair, through processes that were mentioned above.

It should be noted that access to bio concrete technology is not as utopian as it could be calculated, since the procedure for the creation of concrete would remain the same, but to this must be added the application of bacteria for self-repair in the future.

Bioconcrete in Colombia

Bio concrete as a major player in the road and urban infrastructure development

Bio concrete is a wonderful agent that could generate enormous development in countries whose infrastructure is still in its infancy. That is countries that have been called third world countries because their development has not been so noticeable or accelerated. Bio concrete could mean an opportunity for road constructions and the elevation of buildings to gain strength since one of the major limitations for the construction and application of concrete is the cost of maintenance and repair materials.

The most notorious advantage for which concrete has been called revolutionary has been its self-repairing characteristic, since one of the biggest problems that engineers have had to face is the calculation of the resistance of structures to factors such as humidity, which in the case of self-repairing concrete does not present any threat, on the contrary, it awakens microorganisms that begin to fulfill their function by feeding on calcium lactate and secrete limestone as a result of the process.

Temperature is one of the variables to consider for concrete self-repair because it has been shown that the process is less effective at very low or high temperatures. The cracks were not sealed at 4°C, and there was much less sealing at 35°C than at 23°C, indicating that temperature is an important factor in self-repair. In the case of Colombia, its application would be less disrupted by this factor because, due to its geospatial location, ambient temperatures do not reach the extremes where performance is severely impacted.

The application to road infrastructure would have some limitations because rising temperatures cause a lower rate of repair. At 35°C, the filling was observed in both the control and bacteria specimens, with a maximum thickness of 0-15 mm, indicating that at this temperature, there was an autogenous self-repair effect of the concrete rather than a sealing by the bacteria.

A concurrent problem for the construction of roads in Colombian territory is the variation in the terrain, i.e., the accidentalness of the terrain can cause the concrete to fracture more frequently and easily, so implementing a self-repairing concrete could generate greater benefits than the mechanisms currently used, which are not only expensive but also have a higher fracture rate. The likelihood that road maintenance will be significantly reduced raises the prospect of using bio concrete, not only because of its repair capacity

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but also because it has been demonstrated that the presence of bacteria in concrete improves its resistance.

The majority of repair costs are incurred as a result of cracks that appear during the useful life of the concrete. As a result, having this technology will save you money, time, and inconvenience for the residents of your properties. Although the cost of producing concrete with these characteristics is three times that of standard concrete, this is offset by the avoidance of repair costs due to cracks over time. It is not affected by the chemical composition of rain with a certain degree of acidity; thus, during rainy seasons when there is sufficient concrete-fluid contact time, the water does not penetrate due to the permeability of the concrete (which is a function of the fissures or cracks present). Permeability is reduced in self-repair concrete because cracks are reduced from 0.5 mm to 0.35 mm in width, which is why this type of concrete has better hardening properties than conventional concrete.

Although the application mentioned in the previous section is more focused on building structural constructions, there are also many benefits of self-repairing concrete for road applications. It was previously mentioned that the production cost was slightly higher than normal concrete, but the positive side that this provides is the elimination of unnecessary maintenance, which is used to prevent micro-cracks from becoming a much bigger problem. Bio-concrete has the potential to save billions of dollars in the maintenance of structures such as buildings, bridges, and dams.

The advantages of bio concrete are not limited to the reduction of budgets for maintenance and repair materials; it also provides advantages such as durability and safety, as it has been demonstrated that the useful life of the bacteria mixed with the concrete can last up to 200 years. This type of bacteria can go dormant for up to 200 years and reactivate only when necessary. Because of its thickness, the thermal insulation it provides is greater than that of other materials, allowing for greater temperature stability within the construction and reducing the time it takes for bacteria to repair the concrete.

When cracks appear in buildings made of this material, the bacteria that live within them are exposed to the elements, most notably water. The moisture that enters the cracks awakens the microorganisms, which begin to feed on calcium lactate and secrete limestone as a byproduct of their digestion. This material, among other things, seals cracks in bio-concrete in as little as three weeks.

Despite the benefits that this type of concrete provides, there are some limitations to what it can do. One of the most notable is the way it can repair concrete. Although it is stated that there is no limit to the length of the crack, if it exceeds the allowed width, it will not be able to repair itself. Centimeters to kilometers. However, there is a width restriction: cracks must not be wider than 8 millimeters.

Despite this limitation, it has been demonstrated that bio-concrete offers a novel solution to one of the world's most pressing issues: seismic activity in various parts of the world. Because bio-concrete is more resistant, durable, and has the ability to self-repair due to bacteria, its use could usher in a new era of more durable and welcoming structures. As part of the bio-concrete evaluations, the material was used to construct irrigation canals in Ecuador, a seismically active country. Although it is more expensive than traditional concrete, the cost savings on maintenance are quickly realized.

Finally, it should be noted that rather than disadvantages, bio concrete offers multiple benefits that extend from its application to future times, due to its resistance, self-repair, and durability over time. As highlighted at the beginning of this research, an answer has always been sought to the durability of the constructions that we admire as wonders, since they have been standing for centuries, without the need to replace their parts, which led to finding a compound as complete as the self-repairing concrete.

Its application in Colombia would set a precedent without equal since it would drastically improve the quality of the road infrastructure that is currently in decay and whose sustainability is very high, as well as the application of structures in the urban hull of areas in the growth and cultural and commercial development.

Conclusion

First of all, although bio concrete has a slightly higher price than common concrete, maintenance costs are lower, because due to its ability to seal cracks and fissures that may occur in it, it is not necessary to carry out processes such as welding, injection, or sealing with other materials such as epoxy resins, which will eventually require new maintenance, but the environment itself will be in charge, together with bacteria, of sealing this problem of the structures free of charge.

The environmental impact of this material is great because complementing what was said above about the decrease in maintenance costs, the self-repairing concrete avoids the need for the application of more concrete and cement for repairs so that the production of types of cement in the country could be reduced considerably and likewise the pollution and damage generated by its production in Colombian ecosystems.

Self-repairing concrete is evidence that nature and life will always be indispensable factors in the solution of problems because considering that concrete has bacteria, it could be said that concrete has life and solves its problems with that life.

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And finally, the implementation of this material would prolong the life of the country's constructions and buildings, because it has certain characteristics such as resistance to adverse climates and fire, its flexibility, sustainability, comfort (thermal insulation, better air quality in buildings, and temperature stability) and capacity to acquire an infinite number of forms, in addition to its main capacity for self-repair; thus reinforcing the dream of giving Colombians firm, safe and quality structures.

Taking into account all the factors, characteristics, and conditions of self-repairing concrete and its application in the various fields of civil construction, it can be concluded that there are more advantages than disadvantages of using bio concrete in Colombian constructions, since its economic, social, and environmental benefits are greater than the deficiencies it may present.

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