© 2023 IJNRD | Volume 8, Issue 5 May 2023 | ISSN: 2456-4184 | IJNRD.ORG

IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

STUDY ON SELF HEALING CONCRETE BY THE USE OF BACILLUS SUBTILIS BACTERIA

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Abstract: Cracks in concrete structures is a universal issue and a very common phenomenon due to relatively low tensile, poor construction, temperature variation, creep, poor design of building etc. Water infiltration into concrete structures can be a significant issue, decreasing their overall durability and making them more susceptible to damage over time. This is because water can seep into the concrete, causing it to deteriorate and leading to corrosion of any steel reinforcement that comes into contact with it. Over time, this can compromise the integrity of the entire structure, creating potential safety hazards and reducing its overall lifespan. By addressing water infiltration through innovative approaches like self-healing and bacterial concrete, we can help to ensure that our infrastructure remains strong and resilient for years to come. Depending upon the cracks of the building, maintenance and treatment is provided. Revolutionizing the field of construction, self-healing concrete represents a ground-breaking solution to one of the most pressing challenges facing the industry: the issue of cracks and deterioration. By leveraging the inherent self-repairing abilities of certain materials, engineers have developed a way to create concrete that can heal itself, preventing further damage and extending the lifespan of structures. This innovative concept holds the promise of creating a more sustainable and resilient built environment, one that can withstand the challenges of our rapidly changing world. This remarkable ability of materials to heal themselves automatically has been incorporated into concrete, allowing it to repair its own cracks and prevent further damage. Bacteria is used as a healing agent as it forms calcium carbonate when it comes in contact with the water which seeps in due to the cracks. Bacteria such as Bacillus subtilis, Bacillus megaterium, B. pasteurii are commonly used in the experiments done previously. Culture of the bacteria demands a particular temperature and a particular time period. In recent studies, researchers have discovered that integrating bacteria into concrete can result in remarkable improvements to its strength, water absorption, and resistance to environmental hazards like freeze and thaw cycles. In fact, bacterial concrete has been shown to outperform conventional concrete in terms of permeability and durability. By harnessing the power of nature in this way, we can create stronger, more resilient structures that are better equipped to withstand the challenges of our changing world.

***IndexTerms* - Concrete, Cracks, Bacteria, Self-healing, Strength, Bacillus subtilis**

INTRODUCTION

As one of the most ubiquitous materials on the planet, concrete has played an integral role in the construction of our modern built environment. Composed of a blend of cement, sand, coarse and fine aggregate, and water, concrete is renowned for its strength in compression. However, due to its inherent weakness in tension, concrete is also prone to cracking and other forms of damage over time. As such, there has been a great deal of research and development focused on finding new ways to enhance the durability and longevity of this vital material, including the use of self-healing and other innovative techniques. By pushing the boundaries of what is possible with concrete, we can help to create a more sustainable and resilient world for generations to come. Due to this, it requires help in resisting tensile stresses rise by bending forces from applied loads which would result in cracking and ultimately structure failure. Self-healing is defined as the ability of a material to repair its damages autonomously without any external interference. Self-healing can be of two types given below: -

- Autogenous
- Autonomous

1. Autogenous self-healing

Autogenous self-healing is a fascinating phenomenon that occurs when a material can repair itself using only its original components, without the need for external intervention. In the context of concrete and other cementitious materials, the ability to self-heal is deeply rooted in their unique chemical composition, and is dependent on optimal environmental conditions. By leveraging this inherent property, we can unlock a new era of durable and sustainable infrastructure.

2. Autonomous self-healing

To achieve autonomous self-healing in materials like concrete, engineers must incorporate unconventional modifications into the material matrix to create a self-repairing function. One popular method for delivering healing agents directly to cracks is through encapsulation, which allows for in-place repair. There are two distinct approaches to encapsulating healing compounds: discrete and continuous. The choice of encapsulation method determines the extent of damage that can be treated, the effectiveness and frequency of healing, and the speed at which the material recovers. By leveraging these innovative techniques, we can unlock new possibilities for resilient and self-repairing infrastructure.

Advantages

- The use of self-healing concrete enhances the strength of concrete.
- It offers great resistance against freeze and thaw effects.
- The chances of corrosion of reinforcement are reduced to negligible.
- It has lower water absorption when compared to traditional concrete.
- Overall maintenance cost of self-healing concrete is low.

Disadvantges

- There is no design mentioned in IS Codes for the preparation of self-healing concrete.
- Initial cost of bacterial concrete is higher than conventional concrete.
- The germination of bacteria is not suitable in every environment.

Materials and methods

1) **Cement-** In this study, a conventional concrete mix was used, with Ordinary Portland Cement (OPC) of 53 grade as the binder material, confirming to the physical and chemical properties as per IS:12269 (1987b).
2) **Fine aggregate**- To prepare the mix, river sand passing through 4.75mm IS sieve and confirming to zone-1 of IS:383 (1987a) was used as fine aggregate, with a specific gravity of 2.3.
3) **Coarse aggregate**- Crushed stones of maximum size 20mm and retained on 4.75mm IS sieves were used as coarse aggregates, with a specific gravity of 3.13.
4) **Water**- Potable water was used for conventional concrete, while bacterial water consisting of 10^5 cells of Bacillus megaterium / ml of water was used for the self-healing concrete mix.
5) **Metal sheet**- To induce an artificial crack in the unhardened concrete specimen, a thin metal sheet of thickness 0.3mm was used, which was inserted up to a depth of 10mm.
6) **Bacteria**- The self-healing capability of the concrete mix was tested using Bacillus subtilis, an aerobic, rod-shaped Gram-positive bacterium that is commonly found in soil and not harmful to human beings. Bacillus subtilis was chosen due to its faster growth rate and shorter fermentation cycle compared to other bacterial species, making it a suitable candidate for self-healing concrete applications.

Overall, this study utilized a unique combination of conventional concrete materials and bacterial water to develop a self-healing concrete mix, with the use of an artificial crack and Bacillus subtilis to evaluate its self-healing capabilities.

Process of manufacture of concrete

1) BATCHING- Batching is defined as the measurement of materials for making concrete. Batching is of two types, volume batching and weight batching. In this test, weight batching is done for the cement, sand and aggregate. Volume batching is done for the bacillus subtilis that we have used. 15% by volume bacillus subtilis is used.
2) MIXING- Mixing of the materials is important for the preparation of uniform concrete. Mixing is done to ensure that the mass becomes homogeneous and uniform in color.
3) TRANSPORTATION- Transportation is not required as we have prepared the concrete in the laboratory and all the tests are done in laboratory.
4) PLACING- To yield optimum results, concrete must be placed in systematic manner.
5) COMPACTION- For expelling the entrapped air from the concrete, compaction of concrete is done. If this air is not removed from the concrete and remains in it, the concrete loses its strength.
6) CURING- Curing is defined as the process of keeping the concrete moist so that the hydration of cement can continue and develop the desired concrete properties.

Tests on hardened concrete

A. Destructive tests on hardened concrete

As a fundamental building block of modern infrastructure, concrete plays a crucial role in construction, making it essential to prioritize the maintenance of its quality throughout the building process. The strength of hardened concrete increases over time, and understanding its behaviour and quality is essential for constructing safe and durable structures.

This testing method is particularly useful for large-scale concrete production, as it allows for investigations into service life and potential design weaknesses that may not be evident under normal working conditions. In addition, destructive testing is straightforward to carry out, easy to interpret, and provides a wealth of information for researchers and engineers alike. By employing this method, we can continue to improve the quality and longevity of concrete in construction projects worldwide.

1) Split tensile strength Test
2) Compressive strength Test

1. Tensile strength test of self-healing concrete

Although concrete is a popular construction material, it is susceptible to cracking due to its inherent brittleness and weakness in tension. When subjected to tensile stresses, concrete can crack and ultimately fail if the applied load exceeds its tensile strength. This is a significant concern for construction projects, as cracks in concrete can compromise the safety and structural integrity of buildings, bridges, and other infrastructure. Therefore, it is crucial to conduct tensile strength tests to determine the material's capacity to withstand tensile forces. The splitting tensile strength test is a critical method for assessing the tensile strength of concrete, as it involves the application of compressive forces to a cylindrical sample until it splits along the vertical diameter. This test provides a reliable measure of the concrete's ability to resist tensile stresses, which is essential for ensuring the structural integrity and safety of construction projects.

This indirect method of testing the tensile strength of concrete requires at least three samples to be tested, and the average value is calculated to obtain an accurate measure. The primary objectives of conducting this test are numerous, including determining the tensile strength of concrete, providing information on the use of sand and aggregate, and assessing the uniform stress distribution.

In addition to its primary purpose of measuring tensile strength, the splitting tensile strength test is also a valuable tool for studying the behaviour of concrete under tensile forces. By analysing the fracture patterns and failure modes of the test specimens, engineers can gain insights into the microstructure of concrete and develop more effective designs and construction methods that can better withstand tensile stresses. By understanding the tensile strength of concrete, we can ensure the durability and safety of structures worldwide.

2. Compressive strength test of self-healing concrete

The compressive strength test is a vital component of assessing the quality of hardened concrete. It provides valuable information about the material's characteristics and helps in controlling the quality of cement concrete works, ensuring that they meet the required standards. This test is also crucial in determining whether the concreting has been done accurately or not, helping to prevent future problems and failures.

The compressive strength of concrete is an essential factor to consider in construction projects, as it determines the material's ability to withstand loads on its surface without failing, cracking, or deflecting. It is influenced by various factors, including the water-cement ratio, the strength of the cement used, and the quality of the concrete material. However, ensuring high compressive strength also requires stringent quality control measures during the production of concrete, as even minor variations in the mix or curing conditions can significantly impact the material's strength and durability.

By conducting compressive strength tests, we can identify any weaknesses in the concrete and take necessary corrective actions. This ensures that structures built with concrete are safe and durable, and can withstand the loads they are designed to carry. In this way, the compressive strength test is an essential tool in the construction industry, helping to maintain high standards of quality and safety.

Compressive Strength Formula

The compressive strength of concrete is calculated by the following formula: -

Compressive Strength = Load / Area of cross-section

B. Non-destructive test of hardened concrete

1. Rebound hammer test
2. Ultrasonic pulse velocity method

1. Rebound Hammer Test

The rebound hammer test is a widely used non-destructive testing (NDT) method that helps assess the quality and uniformity of concrete structures. It involves using a handheld device to strike the surface of the concrete and measuring the rebound energy, which is then used to calculate the surface hardness and, consequently, the compressive strength of the material.

In addition to providing information on the uniformity of the structure, the rebound hammer test is also beneficial in reducing corrosion in the back rete. This is due to the strong bonding of materials and the closure of pores resulting from calcite formation. NDT studies have shown a significant increase in the surface strength of normal concrete when tested using the rebound hammer method.

Moreover, the bacterial effect on the closure of pores is currently being studied, with a crack width of 50 micrometres observed before failure. This research has the potential to lead to further improvements in the durability and longevity of concrete structures. Overall, the rebound hammer test is a vital tool in the assessment of concrete quality and can help identify potential weaknesses before they cause significant problems. Its non-destructive nature makes it a valuable testing method that can be used on both new and existing structures.

2. Ultrasonic Pulse Velocity

To assess the effect of microbial activity on the properties of concrete, specimens were cast using M20 designations and standard mix design procedures. The results showed a significant increase in compressive and flexural strength, indicating that the microbial effect during the curing period played a beneficial role in strengthening the concrete.

However, the effect of pH on the bacterial species has yet to be studied. The pH of the concrete was found to be in the range of 7.6-9.8, which was measured using a standard pH probe. This suggests that the pH level of the concrete is conducive to bacterial growth, and further research is needed to understand the relationship between pH and microbial activity in concrete.

Interestingly, there was a noticeable difference in crack width between normal concrete and bacterial concrete. The latter showed less crack depth and width, which was analyzed using UPV UX4000 Instar make. These findings suggest that the use of microbial activity in concrete production could have significant benefits in terms of improving its durability and reducing the likelihood of cracks and other structural problems.

Results of self-healing concrete cube test

Tensile strength test in MPa

Days	3	7	28
Conventional Concrete	2.76	3.72	4.73
5% Bacterial Concrete	2.808	3.77	4.8
10% Bacterial Concrete	2.9	3.90	4.97
15% Bacterial Concrete	3.01	4.04	5.15
20% Bacterial Concrete	3.07	4.131	5.26

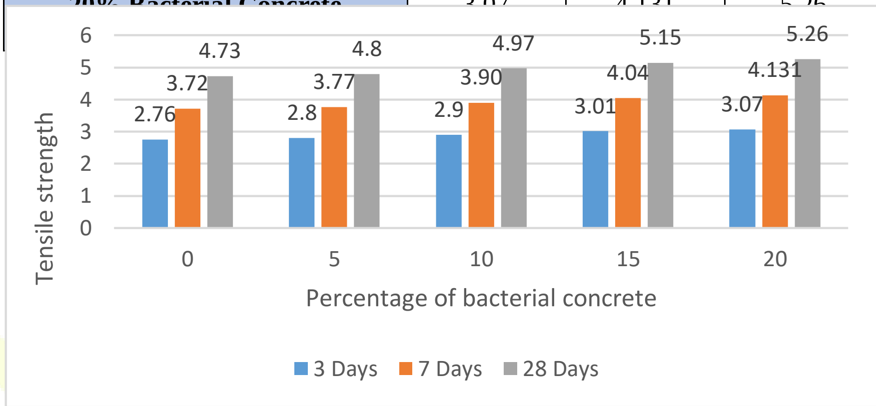

Fig:1 Comparison of tensile strengths between conventional concrete and bacterial concrete in MPa

Compressive strength test in MPa

Days	3	7	28
Conventional Concrete	15.65	28.25	45.85
5% Bacterial Concrete	16.10	29.01	47.17
10% Bacterial Concrete	17.26	31.10	50.57
15% Bacterial Concrete	18.5	33.4	54.2
20% Bacterial Concrete	19.24	34.84	56.54

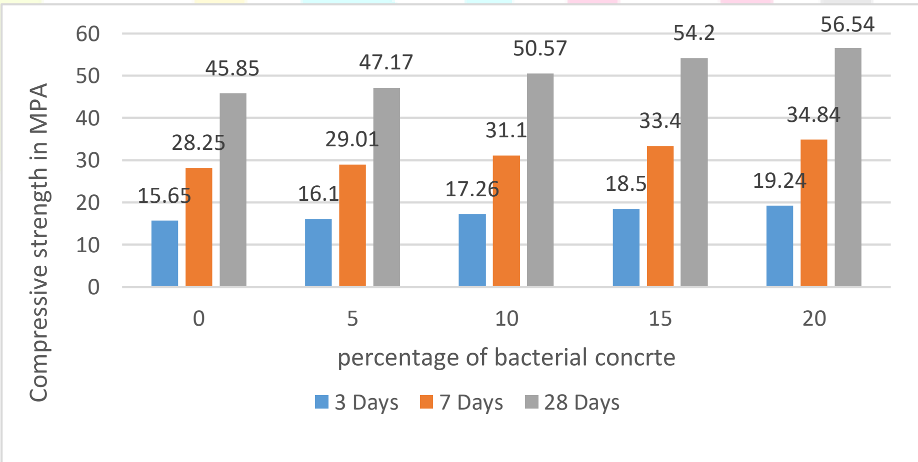

Fig.:2 Comparison of compressive strengths between conventional concrete and bacterial concrete in MPa

Future scope

Microbial concrete is a cutting-edge technology that has gained tremendous popularity in the field of Bio Geo Civil Engineering. It has proven to enhance the durability of cementitious materials, upgrade sand properties, repair limestone structures, seal concrete cracks, and produce highly durable bricks. This innovative technology has the potential to revolutionize the construction industry by providing low-cost, sturdy roads, high-strength buildings with exceptional bearing capacity, long-lasting river banks, erosion prevention of loose sands, and low-cost, durable housing.

One of the most significant advantages of microbial concrete is its eco-friendliness. Unlike conventional building materials, which produce high levels of greenhouse gases and consume vast amounts of energy during production, microbial concrete is a self-healing and energy-efficient technology that utilizes microbes for the remediation of building materials and improves their durability characteristics. Moreover, the high production costs associated with traditional building materials are a thing of the past with the implementation of microbial concrete.

The potential applications of microbial concrete are limitless, and it is a crucial step towards sustainable infrastructure development. With the use of this innovative technology, we can create a more environmentally friendly and cost-effective built environment while reducing the negative impact of conventional building materials on our planet.

Summary

According to all the above discussion and research we get the various perspectives about the self-healing concrete: -

1) Self-healing concrete compressive strength, varies 13-15 % more than the conventional concrete.
2) Self-healing concrete is very much durable w.r.t normal concrete due to its cementious property and use of bacterial concrete, it exists more than 200 years.
3) It cures the cracks between 0.05 mm to 0.87mm but not efficient for large cracks.
4) Minor negative impact on the environment.
5) High initial cost but cost effective in long term.

Conclusion

1) From the studies, it is obvious that we can implement this technology to improve the properties of concrete.
2) When we compare the cost of self-healing concrete and conventional concrete, we found that self-healing concrete is economical for long term solutions.
3) Self-healing concrete is going to revolutionise the construction industry in the future.

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