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Bacteria based Self-Healing Concrete: Review

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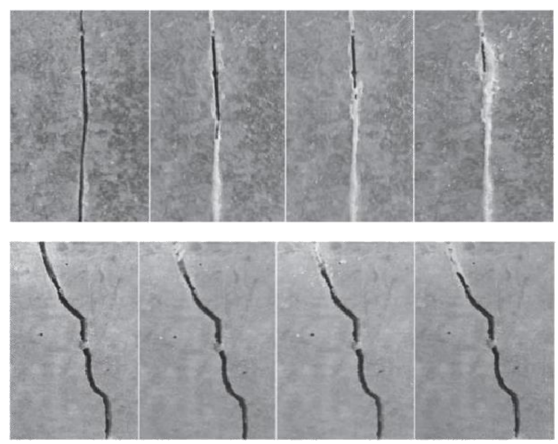
ABSTRACT:- In Concrete, cracking is a common problem developed due to relatively low tensile strength. Cracks in concrete are the main reason for a decreased service life of concrete structures. Proper and immediate treatment should be done in order to prevent expansion of cracks which may eventually be of higher cost. It is therefore more advisable and economical to restrict the development of early age small cracks as expansion to larger width. To overcome these situations self-healing techniques are adopted. The addition of urease producing bacteria along with calcium source results in calcite precipitation in concrete. The freshly formed micro-cracks can be sealed up by continuous hydration process in concrete. The Ureolytic bacteria i.e. bacillus pasteurii which can produce urease to seal the freshly formed micro-cracks by CaCo3 precipitation. This paper aims to review the development of bacteria-based self-healing concrete, its classification, types, mechanism adopted, advantages and disadvantages.

INTRODUCTION:

Concrete as a structural material received extensive use all over the world during the 20th as well as the 21th centuries. The rapid development of ready-mixed concrete is one of the important signs of concrete technological progress and overall quality improvement, but there are some new problems. The most prominent problem is the higher probability of cracking caused by low tensile strength of concrete. In the previous studies, self-healing concrete materials were developed to increase the strength and the life of structure. Bacteria-based self-healing concrete was developed by adding the microbial self-healing agent which has the potential to improve self-healing capacity mainly achieved by bacteria induced mineral precipitations. The process depends on urease producing bacteria which are ubiquitous in nature. The overall reactions may be summarized as follow:

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3NH_2COOH + H_2O$$
$$\rightarrow NH_3 + H_2CO_3H_2CO_3$$
$$\leftrightarrow HCO_3^- + H^+2NH_3 + 2H_2O$$
$$\leftrightarrow 2NH_4^+ + 2OH^-HCO_3^- + H^+ + 2NH_4^+ + 2OH^-$$
$$\leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2OCa^{2+} + Cell$$
$$\rightarrow Cell - Ca^{2+}Cell - Ca^{2+} + CO_3^{2-}$$
$$\rightarrow Cell - CaCO_3^-$$

Adopting bacteria induced carbonate precipitation to fill the cracks is very innovative. In this method, which is a result of biological activities, is pollution free and natural. The microbial precipitation depends on several factors, including: the concentration of dissolved inorganic carbon, the pH, and the concentration of calcium ions and the presence of nucleation sites. Also, when bacteria are used to work for the healing of cracks in concrete, the major hindering factor is the high alkaline environment of concrete, restricting the growth of the bacteria. Therefore, necessary measures need to be taken to protect bacteria in concrete. So, in order to ensure the effective mineral precipitation which could lead to the healing of cracks, care should be taken to meet the prerequisites. It is a new and promising method and currently the research in this aspect focuses more on the durability side while there is a little touch on the mechanical properties and further researches need to be conducted.



Surface images of specimens with crack and after repair

Types of bacteria used in concrete:-

Various selected types of bacteria were used as construction materials. Bacillus was used for the precipitation of calcite on the surface of the concrete. The nutrients for the bacteria which are able to precipitate calcite are calcium sources, phosphorous and nitrogen sources. These bacterial components remain dormant in concrete, when the seepage of water take place the bacterial component react with nutrient to precipitate calcite i.e., $CaCO_3$. Various types of bacteria used in concrete are:-

- Bacillus pasteurized

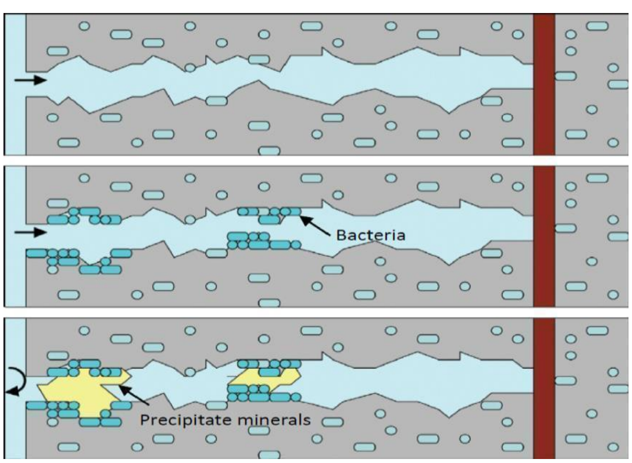
- Bacillus sphaerieus
- Escherichia coli
- Bacillus subtitles
- Bacillus cohnii
- Bacillus balodurans
- Bacillus pseudofirmus

Advantages of bacteria:-

- The self-healing bacterial concrete helps in reducing maintenance and repair costs of reinforced concrete structures.
- Oxygen is an agent that can induce corrosion, as bacteria feeds on oxygen tendency for the corrosion of reinforcement can be reduced.
- Self-healing bacteria can be used in places where human find it difficult to reach for the maintenance of the structures. Hence it reduces risking of human life in dangerous areas and also increases the durability of the structure.
- Formation of crack will be healed in the initial stage itself thereby increasing the service life of the structure than expected life.
- It is pollution free and eco-friendly

Disadvantages of bacteria:-

- Cost of bacterial concrete is higher as compared to conventional concrete.
- Growth of bacteria is not good in any atmosphere and media.
- If the volume of self-healing agents (bacteria and calcium lactate) mixed becomes greater than 20%, the strength of the concrete is reduced.



Schematic scenario of crack-healing by concrete-immobilized bacteria

LITERATURE SURVEY

Mian Luo, Chun-xiang Qian, Rui-yang Li, analyzed the precipitations formed at the cracks surface of the cement paste specimens with Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray Spectrometer (EDS), and then examined by X-ray Diffraction (XRD) In conclusion, the results presented in this study show that the microbial self-healing agent can be used to achieve the goal of concrete crack self-healing. Two types of bacteria were used.

Type 1 - calcium lactate,

Type 2 - calcium formate with bacteria spores

Navneet Chahal, Rafat Siddique, Anita Rajor carried out an experimental investigation to evaluate the influence of sporoscarcina pasteurii bacteria on the compressive strength and rapid chloride permeability of concrete made without and with fly ash. Cement was replaced with three percentages (10, 20 and 30) with fly ash by weight. Three different cell concentration (0, 103,105,107 cells/ml) of bacteria were used in making the concrete mixes. Bacterial calcite deposition observed nearly eight times reduction in chloride permeability; hence the life of the concrete structures can be increased.

Smita G. Khade, Sachin J. Mane developed self-healing system, characterization studies done with different bacterial species, variation in compressive strength of concrete upon bacterial cell concentrations, physical properties of self-healing concrete, potential of bacteria to act as a self-healing agent etc., are observed and identified from the other research works. A specific group of alkali-resistant spore forming bacteria preferably of genus Bacillus are selected and added to concrete or mortar paste for development of self-healing capacity in structures. The conclusions made by research are- (1) Supply of nutrients play a significant role in the bacterial activity in cement mortar.

(2) It is understood that waste water rich in organic sources supply sufficient nutrients for the survival of bacteria. From the results obtained with and without bacterial concentrations in cement mortar cured in water, it is revealed that the incorporated bacteria is playing a major role in strength improvement.(3)The non-uniformity of the strength gain over the period indicates that bacterial activity is highly dependent on the period of curing.

Rafat Siddique, Abir Jameel, Malkit Singh, Danuta Barnat-Hunek, Kunal, Abdelkarim Aït-Mokhtar, Rafik Belarbie, and Anita Rajor study the influence of bacteria on strength and permeation characteristics concrete incorporating silica fume. The cement was partially substituted with 5, 10 and 15% silica fume and with constant concentration of bacterial culture, 10^5 cfu/mL of water. Cement was substituted with silica fume in concrete by weight. At 28 day, nearly 10–12% increase in compressive strength was observed on incorporation of bacteria in silica fume concrete.

On addition of bacteria, water absorption, porosity and capillary water rise reduced in the range of 42–48%, 52–56% and 54–78%, respectively, in bacterial concrete compared to corresponding nonbacterial samples at 28 days. Reduction in chloride permeability of bacterial concrete was observed and the total charge passed through bacterial concrete samples reduced by nearly 10% compared to nonbacterial concrete samples at 56 day of age.

Calcite precipitation on addition bacteria and confirmed by Scanning Electron Microscope (SEM) and X-ray Diffraction (XRD) analysis is considered as the reason for improvement in properties of concrete. Economic study of bacterial SF concrete has also been carried out in that work. The Benefit/Cost Ratio of bacterial SF concrete got reduced with the increase in SF quantity. Compared to control concrete, bacterial silica fume concrete containing 10% silica fume demonstrated highest benefit in improvement in its properties and corresponding highest Benefit/Cost Ratio

J.Y. Wang, D. Snoeck, S. Van Vlierberghe, W. Verstraete, N. De Belie carried out an experimental study. In study it was found that the bacterial spores were first encapsulated into hydrogels and then were incorporated into specimens to investigate their healing efficiency. The precipitation of $CaCO3$ by hydrogel-encapsulated spores was demonstrated by thermo-gravimetric analysis (TGA). The mortar specimens with hydrogel-encapsulated spores, showed a distinct self-healing superiority. The maximum healed crack width was about 0.5 mm and the water permeability was decreased by 68% in average. Other specimens in non-bacterial series had maximum healed crack width of 0–0.3 mm and the average water permeability was decreased by 15–55% only.

Amirreza Talaiekhozani, Mohanadoss Ponraj, Gholam Reza Ziaee, Rosli Mohamad Zin, Muhd Zaimi Abd Majid, Ali Keyvanfar studied the physiological effect of using houses or offices made up of biological concrete on the humans was investigated by the distribution of the questionnaire among students, academic and non-academic staffs of University Technology Malaysia. The results of this study shows that although, people are keen to stay in this type of houses or offices, but they are seriously concerned with the negative effects of houses or offices made up biological concrete on their health. As many of the bacteria used in making biological concrete are pathogenic, so the public concern is understandable. However, the use of non-pathogen bacteria such as bacillus pasteurii can decrease the public concerns about the transmission of illness to humans from the biological concrete. The current research paper can be considered significant for architects and civil engineers to have the insight to look into the psychological aspects of using biological concrete in the field of construction.

Kunamineni Vijay, Meena Murmu, Shirish V. Deo gives a brief description of the types of bacteria used in concrete. The literature shows that Encapsulation method will give better results than direct application method and also shows that the use of bacteria can increase the strength and durability properties of concrete.

Sr. No	Bacteria Used	Results
1	Bacillus Sp. CT-5	Compressive Strength40% More Than The Control Concrete
2	Bacillus Megaterium	Maximum Rate Of Strength Development Was 24% Achieved In Highest Grade Of Concrete 50 Mpa
3	Bacillus Subtilis	Improvement Of 12% In Compressive Strength As Compared To Controlled Concrete Specimens With Light Weight Aggregates
4	Bacillus Aerius	Increase In Compressive Strength By 11.8% In Bacterial Concrete Compared To Control With 10% Dosage Of RHA
5	Sporosarcina Pasteurii	Compressive Strength35% More Than The Control Concrete
6	AKKR5	10% Increase In Compressive Strength As Compared To Control Concrete
7	Shewanella Species	25% Increase In Compressive Strength Of Cement Mortar Compared With The Control Mortar

CONCLUSION:-

Based on the literature, the following conclusions were drawn:-

(1) The study has reviewed different types of bacteria that can be used for healing cracks, use of urease producing bacteria isolates, such as Bacillus subtilis, bacillus pasteuri species in healing of cracks in concrete.

(2) Comparative studies show that there are advantages and limitations about different healing agents and strategies. In order to realize effective and reliable self-healing, care should be taken in choosing a healing agent and a suitable strategy for a specific application.

(3) Due to its eco-friendly and self-healing capacity bacterial concrete has been proved to be better than the conventional concrete.

(4) Bacterial concrete is durable, cost effective and environment friendly.

(5) According to the some researches, some of the bacteria are not good for human health like Leuconostoc mesenteroides, Bacillus amyloliquefaciens, Shewanella species, Pseudomonas aeruginosa, Bacillus megaterium[11] but some other bacteria like bacillus Sphaericus, bacillus pasteurii, bacillus subtilis, and bacillus flexus[6, 9] does not impose any bad effect on human health.

(6) A point should be consider that, as the process of mixing the bacteria in concrete is somewhat complicated, so it requires skilled labors

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