A Review on Self-Healing Concrete

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Abstract - *Concrete has become one of the most popular building materials around the globe. Concrete has a large tendency to form cracks during the service life of the building since concrete is weak in tension. Therefore sufficient repair and maintenance is required so as to mitigate such problems. Even though the prevention of crack formation is impossible, there are a lot of techniques to handle this problem. Self-healing concrete is one of the newest innovations in building because of its ability to repair the cracks by itself. Self-healing concrete is also known as bio-concrete or bacterial concrete which is an eco-friendly, durable and non-pathogenic method which uses bacteria to heal the crack on the concrete by the process of bio-mineralization. The bacteria from the genus Bacillus is widely used for the self-healing purpose the concrete. Calcium carbonate, precipitated by the bacteria as a result of metabolic function of the bacteria results in the sealing of the crack in the concrete. Thus the self-healing concrete improves the durability, strength and serviceability of the concrete structures and also reduces the repair and maintenance cost associated with it.*

***Key Words*: Self-healing, bio-concrete, bacillus, bio-mineralization, compressive strength, tensile strength, flexural strength.**

1. INTRODUCTION

Concrete is a worldwide vital construction material which is absolutely essential for the public infrastructure. It is known that concrete is strong in compression and weak in tension. Cracks in the concrete adversely affects the durability and serviceability of the concrete. The ingress of moisture affects the reinforcement by corroding the steel and the ingress of the chemicals such as chlorides and sulphates affects the durability of the concrete. Recent research has shown that the bacteria from the genus Bacillus can be useful as a tool to repair cracks in already existing concrete structure. Self-healing concrete in general seeks to rectify the flaws causing cracks in concrete. Biomineralization is a novel self-healing technique. It has attracted significant attention to the several researchers. Biomineralization is a metabolic process of formation of hard structures, surfaces or scales by combining minerals with organic compounds of some specific microorganisms. Biomineralization involves various microorganisms, pathways and environments. It is a process which involves precipitation of calcium carbonate (calcite) by microorganisms. This technique is also called microbiologically induced calcite precipitation. Biomineralisation can otherwise stated as a process by which living organisms produce organic/inorganic composite minerals, often achieving remarkable material properties and flexibility from limited range of building blocks. Biomineralisation often happens by controlled deposition of inorganic substance on an existing tissue or biopolymer scaffold. Self-healing concrete is a by-product of biologically produced limestone by bacteria which heals the cracks on the surface of concrete. The self-healing bacteria can lie dormant within the concrete up to two hundred years. When a concrete structure gets damaged water starts seeping into the cracks present in the concrete and the dormant bacteria becomes active on consuming oxygen and converts the soluble calcium lactate into insoluble limestone. The limestone precipitated thus seals the cracks present in the concrete. Hence the durability of reinforcement in the concrete is increased. The process of bacterial conversion takes place either in the interior or exterior of the microbial cell. The pH of fresh concrete is ranges between 10 to 13. The temperature of fresh concrete may raise up to 70 degree Celsius. After the drying of concrete, there may not be enough water. Therefore, the selection of bacteria is important and needs to exhibit high resistance against high pH, temperature, and serious limitation of water. Usually mesophilic microorganisms cannot grow normally in these conditions. Spore forming bacteria from the genus Bacillus is best suitable for such projects.

2. REVIEW OF LITERATURES

M. Monisha et al (2017) have conducted an overview of new development obtained in experimental study on self-healing concrete. An attempt is made in Bacterial-concrete with spore forming, calcite mineral precipitating bacterium “Bacillius subtilis”. Concrete prepared was M20 grade concrete with different bacterial cell concentration such as 10^4 10^5 and 10^6 per milliliter of water. Polyethylene fibre is used as reinforcement and it is kept at constant as 0.4%. The overall development of strength and durability of self-healing concrete using Bacillius subtilis and polyethylene fibre has investigated and compared with that of conventional concrete. The polyethylene fibre were bridging over the crack and crystallization products became easy to be attached to a large number of polyethylene fibre. The optimum strength is found to be at 10^5 bacterial cell concentration. It increases the compressive strength by 13.2%, split tensile strength by 21.4% and flexural strength by 16.04%. The percentage of improvement in strength shows that the self-healing concrete is advantageous [1].

Roshni John et al (2017) have done research to compare the best effect of self-healing of cracks in concrete structures. It has led to the development of a special concrete known as Bio concrete where bacteria from the genus bacillus know as bacillus subtilis (JC3) is used. It is combined with another special concrete known as Super absrobant polymer concrete. It was found that Bacteria Bacillus subtilis plays an important role in increasing compressive strength of conventional concrete by 21.33% for 28 days and 25.78% after 90 days. The optimum cell concentration was found to be 10^5 cells/ml and when the concentration increases more than optimum, the strength started to decrease. Super absorbant polymer which is also called as slush powder, are polymer which can absorb and retain extremely high amount of liquids compared to their own mass. Addition of super absorbant polymer beyond the dosage of 0.5% of cement weight start to decrease the strength of concrete. From SEM & EDM test it is concluded that bacterial concrete produce extra amount of calcium carbonate which improves the compressive strength of concrete [2].

Mohanadoss Ponraj et al (2016) conducted research with five different cell concentrations of Bacillus megaterium that is, 10×10^5 to 50×10^5 cfu/ml which is introduced into the concrete structures so as to find out the optimum concentration of bacteria. It was found that there is a significant improvement in the strength in the case of 30×10^5 cfu/ml at different ages. The compressive strength of highest grade of bio concrete has improved about 24% as compared to lowest grade which is 12.8% due to calcification mechanism. Microbial calcite precipitation was measured using X-ray diffraction analysis, visualized by scanning electron microscopy and analysed by using energy dispersive spectrometer. It was found that the optimum concentration of Bacillus Megaterium has a positive effect on high strength concrete structures and it is clear that mineral precipitation has a positive effect to enhance the resistance. It is found that optimum concentration of bacteria has a potential on high strength concrete structures. The consequences of this research provides a significant and innovative contribution for understanding about the effects of bacteria on the performance of concrete structures. Therefore, the bio concrete using Bacillus megaterium can be recommended to be used as a green building material in the construction industry as a construction material against the process of degradation [3].

Deepika.B, et al (2016), made an experiment on the study on strength of bacterial concrete in Bacillus Megateerium. In this paper an investigation is made on the compressive strength and split tensile strength of the bio concrete. In this research different mix proportions for M30 grade of concrete with addition of bacteria Bacillus Megaterium of 5g in 1lit/m3 of water is incorporated. The proportions of ingredients of the control concrete of grade M30 was obtained by mix design as per IS code. Workability of fresh bio concrete was determined by the slump test according to Indian standards. The typical size of cube 150mm×150mm×150mm was used for the determination of the Compressive strength. Split tensile strength was done using the cylinder with dimensions 150mm diameter and 300mm height. The bacterial concrete using bacillus megaterium could obtain compressive strength, split tensile strength and porosity. The incorporation of more numbers of bacteria in the cracks of the concrete cube results a significant gain of property of bacteria, since the repairing of cracks in concrete is increasing with the increase in the concentration of bacterial quantity. Due to the incorporation of bacteria in concrete, there got a slight increase in compressive strength and split tensile strength. The porosity reduced about 12%. From the results it shows that the Bacillus Megaterium can be safely and easily used in improving the characteristics and performance of concrete [4].

Jasira Bashir et al (2016) carried out an experiment on the Self-healing bio-concrete and an attempt has been made to use different microorganisms so as to observe and compare the strength gain as a result of sprouting of filler materials inside the concrete that is in cement sand matrix pores. Compressive strength test, split tensile strength test and flexural strength test are conducted to evaluate the concrete strength. Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) analysis is further carried out to show the involvement of the isolated ureolytic bacteria in calcium carbonate precipitation. From the tests carried out on various specimens of bacterial concrete using different bacteria, a proper comparison could be made for analyzing strengths of different specimens of bacterial concrete using different bacteria with that of convention concrete. The results obtained from the experiment concludes that when water seeps into concrete cracks, the dormant bacteria gets into activated state by the process of metabolically mediated calcium carbonate precipitation and it increases the strength of bio concrete as compared to the conventional concrete. It is found that Bio concrete is durable, eco-friendly and offers better resistance to freeze thaw and also for corrosion. Crack remediation using bio-concrete is better than epoxy treatments and other external treatments. The percentage increase in compressive strength of bio concrete using Bacillus Subtilis is 6.42% for 7 days and 9.16% for 28 days, higher than conventional concrete and the percentage increase in compressive strength of bio concrete using Bacillus Sphaericus is 65.93% and 52.42% for 7 days and 28 days respectively. The percentage increase in compressive strength of bio concrete using Bacillus Pasteurii is 29.99% and 29.97% for 7 days and 28 days respectively. The percentage increase in split tensile strength of bio concrete using Bacillus Subtilis is 38.17% for 7 days and 14.41% for 28 days, higher than conventional concrete. The percentage increase in split tensile strength of bio concrete using Bacillus Sphaericusfor is 31.14% and 2.76% for 7 days and 28 days respectively. The percentage increase in flexural strength of bacterial concrete using Bacillus Pasteurii for is 17.34% and 11.18% for 7 days and 28 days respectively [5].

B. Arthi et al (2016) have studied on the strength and self-healing characteristics of Bacterial concrete. This project shows the results of an experimental investigation for evaluating the influence of two bacteria Bacillus Subtilis and Bacillus Licheniformis on the compressive strength, split tensile strength, flexural strength, water absorption and its self-healing properties. Bacterial concentration 10^5 cells/ml cells/ml are added and tests were conducted at 7, 14 and 28 days. The compressive strength of concrete cubes using Bacillus Subtilis has been increased upto 8% and using Bacillus Licheniformis has been increased upto 15%. The compressive strength of Bacillus Licheniformis is 46.66% of Bacillus Subtilis. The split tensile strength of concrete cubes using Bacillus Subtilis has been increased upto 6.66% and for Bacillus Licheniformis it has been increased upto 12.69%. The split tensile strength of Bacillus Licheniformis is 47.52% of Bacillus Subtilis. The flexural strength of concrete cubes using Bacillus Subtilis has been increased upto 6.87% and Bacillus Licheniformis has been increased upto 9.25%. The flexural strength of Bacillus Licheniformis is 25.73% of Bacillus Subtilis. The water absorption value of concrete has been decreased upto 46.93% by using Bacillus Subtilis and 52.04% by using Bacillus Licheniformis. The water absorption of Bacillus Licheniformis is 9.82% of Bacillus Subtilis. From the above it can be concluded that Bacillus Subtilis and Bacillus Licheniformis can be easily used and safely handled in improving the strength and permeability characteristics of concrete [6].

Vidhya Lakshmi et al (2016) conducted an experimental investigation on self-healing bacterial concrete giving information about improving the durability of the concrete structures by incorporating bacterial cell and other required nutrients for the process known as bio-calcification where the micro-organisms precipitates calcium carbonate (Calcite) layer thus sealing the cracks. The materials used in this experimental work are ordinary Portland cement of 53 grade, coarse aggregate of nominal size 20mm, river sand, calcium lactate and bacteria from the genus Bacillus Pasteurii. Concrete mix proportions used was in the ratio 1:1.5:3 for the preparation of specimens. In comparison with the conventional concrete it is found that the compressive strength of concrete cubes casted with the bacteria is similar. The maximum amount of calcium carbonate precipitation occurred in the area near to the surface of the cracks in concrete cubes. This is because of the fact that the bacterial cell growth is higher in the presence of oxygen and precipitation of calcium carbonate is higher around the surface area of the cube. The corrosion of the reinforcement caused due to the ingress of gases, liquids and other ions can be ceased and thus the permeability of the concrete can be reduced and thus the durability of the structure is increased [7].

Luo Mian, et al (2015) have done research on the efficiency of concrete crack-healing, based on biological carbonate precipitation. The self-healing agent consisted of substrate and bacteria and spore-forming alkali-resistant bacteria were used for the research. Crack-healing capacity of the cement paste specimens with this biochemical agent was studied. The main study carried out was for finding the reduction in permeability after calcite precipitation. After performing compression test, the cracked specimens were then immersed in water for self-healing incubation. The specimens were taken out after 7 day and 28 day of immersion in water and carried out the permeability test. The water permeability test result demonstrate that the bio calcification process can significantly decrease the water permeability of the cement paste specimens. SEM and XRD analysis results shows that the white precipitation in cracks is because of calcium carbonate, which displays as spherical crystal morphology. It was found that the crack with a width of 0.48 mm was completely healed by white precipitation of calcite after for 80 days. The water permeability of specimens with the biochemical agent decreases by 84% after 7 days and 96% after 28 days of immersion in water. Thus concluded that the bacteria-based concrete appears to be a promising approach to increase durability of the concrete [8].

Santosh Ashok Kadapure et al (2016) have done a laboratory investigation on the production of sustainable bacteria-blended fly ash concrete. Fly ash has been used as an alternative as a replacement of cement. This work aims to develop a sustainable fly ash concrete by blending with varying the bacterial concentration. The incorporation of Bacillus sphaericus in concrete increases the mechanical and durability properties of concrete. The Bacillus sphaericus was able to grow at pH of 9 to 12. Hence, the bacteria is called as alkaliphilic spore-forming bacteria, since it is able to grow above 9 pH. The concrete specimens were tested after 7 days and 28 days of curing for compressive strength, split tensile strength, shear strength and permeability test. The results showed that bacterial concrete has a significant effect in reducing permeability property in the presence of fly ash. Test results demonstrate that the combination of fly ash and microbes leads to further enhancement of durability properties of the concrete structure. Fly ash concrete was found to be having similar properties with that of conventional concrete at 28 days of curing. The combination of 30% fly ash and 10^5 cells/ml of Bacillus sphaericus would be an economical approach to get similar mechanical properties as that of conventional concrete [9].

Smitha et al (2016) conducted a research on performance enhancement of concrete through bacterial addition. The process behind bio mineralization is called micro biologically induced calcite precipitation (MICP). The main process is the microbial urease, hydrolyzes urea, to produce ammonia and carbon dioxide and the ammonia released in surroundings subsequently increases the pH which leads to the accumulation of insoluble calcite precipitation. Different types of bacteria from the genus bacillus can be used for preparing the bacterial concrete and the spore forming gram positive bacteria gives the most effective and desirable results. The spore forming bacteria can remain in concrete for about 200 years. But the other chemicals which are used for crack repairing will remain for one application only. They found that the bacterial concrete prepared with admixtures such as silica fume, fly ash etc. gives better mechanical property and durability property. They have also found that in the case of cracks up to 0.2mm size, self-healing of cracks is much effective [10].

Chithra. P Bai et al (2016), have done an experimental investigation on the strength properties of Bacterial concrete with fly ash. For this research, the bacteria Bacillus Subtilis was used with different cell concentrations of 10^3 10^5 and 10^7 cells/ml for preparing the fly ash based bacterial concrete. Cement was partially replaced by 10%, 20% and 30% of fly ash by weight for making the concrete. M30 grade concrete was prepared. Tests like Compressive strength, Split tensile strength, Flexural strength and Ultrasonic Pulse Velocity were carried out after 28 days and 56 days of curing. It was found that the maximum compressive strength, split tensile strength, flexural Strength and Ultrasonic Pulse Velocity values were found for 10% fly ash replacement. The maximum compressive strength, split tensile strength, flexural strength, and Ultrasonic Pulse Velocity values were found for the bacteria cell concentration of 10^5 cells/ml for the bacterial concrete. The increase in the mechanical properties of fly ash concrete is because of the precipitation of calcium carbonate in the micro environment by the bacteria Bacillus Subtilis [11].

Jagadeesha Kumar B G et al (2013) have carried out the effect of bacterial calcium carbonate precipitation on compressive strength of mortar cubes. This paper is about the experimental investigations on mortar cubes which were subjected to bacterial precipitation by different bacterial strains. It also evaluate the influence of bacterial calcium carbonate precipitation on the mortar cubes on 7 days, 14 days and 28 days of bacterial treatment. Three bacterial strains Bacillus flexus, Bacillus pasteurii and Bacillus sphaericus were used for the research. The cubes were immersed in bacterial and culture medium for 28 days with control cubes immersed in water. After 28 days of curing the specimens were tested for compressive strength. The result shows that there is an increase in the compressive strength. Among the three strains of bacteria, the Bacillus flexus, has shown maximum compressive strength than the other two bacterial strains and control cubes. It was concluded that the improvement in compressive strengths is mainly because of the sealing of the pores inside the cement mortar cubes with micro biologically induced Calcium Carbonate precipitation. The three strains of bacteria were tested for urease activity and found all the three strains were urease positive. This was indicated by the change of the colour of the media from yellow to pink, showing urease positive. X-ray diffraction analysis was also done to analyse the chemical composition of the precipitation due to the bio mineralization [12].

3. CONCLUSION

Bacterial concrete is becoming a trend over the special concrete. It is more advantageous due to its self-healing capacity than the conventional concrete with crack repairing. Bio concrete is a novel and ecofriendly method. Calcium carbonate precipitate of the bacteria significantly improves the strength of concrete by filling the voids. By using bacterial concrete the repair and rehabilitation cost of the concrete structure can be reduced. From the literatures it is predicted that the durability of the bacteria is more than the life of the building. This is a very convenient method. This innovation will provide durability to the concrete structure by decreasing the permeability due to the precipitation of calcite by the bacteria through bio mineralization process. But the facts related to the economic matter of the bacterial concrete has to be still to find out.

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