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A Review Paper on Enhancing the Properties of Concrete using Bacteria and Bottom ash under Different Environments

C. Venkata Sai Nagendra
Research Scholar, Dept. of Civil Engineering
UVCE, Bangalore University
Bangalore, Karnataka - 560056

Dr. N. Jayaramappa
Professor, Dept. of Civil Engineering
UVCE, Bangalore University
Bangalore, Karnataka - 560056

***Abstract*— In construction field, concrete is viewed and identified as a source of the nation's infrastructure and indirectly of its economic growth and stability. It is prone to external conditions and, as a result, cracking occurs in the material. There are also cracks due to various factors, such as the application of heavy loads (when the element's strength is not supported), shrinkage and creep, etc. Crack repair relies on the width of crack produced on the material and is categorized into two groups, such as minor and major cracks. Minor cracks may be sealed with the use of external agents, and for major cracks human intervention is required. Cement, Fine aggregate (River Sand), Coarse aggregate and water are the primary components of construction. River sand is obtained from riverbeds for the construction of buildings and the continuous excavation results environmental hazards. This paper provides a review on usage of external agents like bacteria (bacillus subtilis) in concrete that tends to heal the cracks by itself and the use of substitute materials such as bottom ash (fine aggregate replacement) in concrete that involves upcoming improvements in concrete materials that pave the way for some of the alternative materials to be used as a composition of concrete ingredients. The present paper gives a brief review on mechanical and durability properties of concrete using bacteria and bottom ash under different environments like water and saturated soil.**

Keywords*—Cracks, Bacteria (bacillus subtilis), Bottom ash, Saturated soil, Mechanical and Durability properties.

I. INTRODUCTION

Concrete is vulnerable to corrosion and cracks, and the consequent damage and loss of strength requires immensely expensive remediation and repair. Therefore, there is a need for special concrete to react to crack formation, which led to research and development of self-healing concrete. This type of concrete can be made by using some external agents like silica gel, bacteria etc. Among all external agents used in concrete, bacillus subtilis is one of the major agent which helps the concrete to heal maximum width by itself when added to the concrete at a particular concentration. Cultured bacteria solution in concrete not only heals the crack but also helps to improve mechanical and durability properties. By incorporating bacteria solution in concrete doesn't develop self-healing property because the specimens or elements required particular incubation environment like water to obtain that property. Once the suitable environment is provided for the elements then the bacterial solution in the presence of calcium lactate reacts with water resulting in calcium precipitation which heals the concrete. From earlier literature studies, it is recommended using bacteria of a suitable concentration in concrete which improves mechanical and durability properties and develops self-healing property. But the present study is an experimental research which is used to determine the suitable percentage or concentration of bacteria required to improve target strength from lower grade to higher grade (M20 to M25. Etc.,) and will also the development of self-healing property will be studied under different incubation environments. The main objective of the study is whether the bacterial solution is enough to improve target strength or else the combination like bacterial solution and bottom ash (Partial replacement of fine aggregate) will improve the results will be determined at different incubation environments.

A. Bacteria

Microorganisms are a heterogeneous group of several distinct classes of living creatures. Originally, they were classified as plant and animal kingdoms. As this proved unsatisfactory, they were listed as members of the Third Kingdom, the Protista. Based on variations in cellular organization and biochemistry, the Protista kingdom has been split into two classes of Prokaryotes and Eukaryotes. Bacteria and blue green algae are prokaryotes, while fungi, other algae, mucosa and protozoa are eucaryotes (C k J Paniker, 2005). Based on their form, the bacteria are categorized into multiple varieties i. Cocci (from kokkos which means berry) are circular or oval cells ii. Bacilli (from the baculus meaning rod) is a rod formed by cells iii. Vibrios are comma shaped curved rods, derived from their name characteristic's vibratory motility. iv. Spirilla are rigid spiral forms. v. Spirochetes (from speira which means coil and chaite which means hair) are curving spiral forms vi. Actinomycetes are the branching of filamentous bacteria, so-called because of a fancied similarity to the sun's radiant rays as seen in tissue lesions (from actis meaning rays and mykes meaning fungus) vii. Mycoplasmas are bacteria that are defective in the cell wall and thus do not have a stable morphology. They appear as circular or oval bodies and as interlacing filaments. (Moshtaq talip 2016).

Bacillus subtilis is a gram-positive, rod-shaped bacterium that produces spores. Effective genetic analysis tools have supported B. Subtilis to become a paradigm for the study of spore production and low GC Gram-positive bacteria. B.

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Subtilis can develop in minimal media containing only critical salts and carbon, nitrogen and phosphorus sources. It uses a variety of regulatory mechanisms to regulate gene expression for both biosynthetic and degrading pathways. Growth and division need the synthesis and alterations of the thick wall around the bacterial cell. All species in the bacillus genus can precipitate calcium carbonate with the assistance of various nutrients such as calcium lactate, nitrogen, phosphorus, calcium acetate, sodium, tryptone peptone, urea, yeast extract, etc. This can be useful in concrete where the core idea is to use calcium carbonate precipitating bacteria to repair cracks. By introducing the bacteria to the concrete that creates calcium carbonate and which, in turn, fills the pores in the concrete. The choice of bacteria depends on the survival of the bacteria in the alkaline climate. Most microorganisms die in an area with a pH of more than 10. Bacterial strains of the species Bacillus are known to be residing in alkaline conditions and this type of bacteria survives in the alkaline atmosphere by developing spores in very thick walls and can be activated as concrete cracks and water enters in to it (P J Piggot, 2009).

B. Bottom Ash

In the coal combustion process of power plants, two main types of by-products namely, fly ash and bottom ash, are released from manufacturing. Fly ash is blown away by hot air from chimneys and filtered by an electrostatic precipitator. In the meanwhile, the bottom ash is molten and larger with a higher weight due to a larger particle size. This form of ash is precipitated to the bottom of the furnace due to its high weight. All the released fly ash has been utilized in concrete production, and the bottom ash has been disposed as waste in landfills, thereby causing environmental pollution. The properties of concrete with the use of coal bottom ash as a partial replacement for river sand is found to be potentially viable material which could be used as a fine aggregate to make durable concrete (Singh et.al.2013).

C. Self-Healing Concrete

Cracks in concrete structures not as it were diminishing outlined benefit life but moreover causes corrosion of steel bar due to weathering activity. A few kinds of human mediation are required to examine and repair the cracks in concrete. In a few cases, however, it is troublesome for engineers to get to harmed destinations for repair work since of their area and/or natural conditions. Examples of the above scenario include underground structural members, tank walls containing extremely hazardous waste and nuclear waste storage facilities. The ability of a substance to restore itself with little or even no external support to recover its attractive mechanical properties after loss or deterioration has occurred is considered as its self-healing property (Wu M, Johannsson B et.al.2012). Biologically healed concrete is an ecologically sound process that can be accomplished by utilizing microorganisms in the design of self-healing concrete. The justification for preferring microorganisms is that they can thrive anywhere, such as soil, acidic springs, water, oil wells, etc. In general, there are three types of microorganisms, including bacteria, viruses and fungi. Out of the types of microorganisms described above, special strain bacteria are the most effective to be used for self-healing concrete because of their ability to precipitate some valuable chemicals to be used in the construction of self-healing concrete. In this process, microorganisms are introduced into concrete by means of different methods, e.g., the introduction of microbial broth in freshly shaped concrete, in spores form, in immovable form on silica gel, in the form of encapsulation and by the use of a vascular network system.

II. LITERATURE REVIEW

Adam Souid et.al.,[1] studied about bio self-healing concrete Incubated in saturated natural soil and the effect of soil incubation is examined whether the self-healing process can be activated in comparison with the conventional incubation environment (water). The mortar was impregnated with Bacillus subtilis and the bacteria were encapsulated in calcium alginate for protection against the phase of processing. The mortar specimens of different mixes were cured in conventional curing for 28 days, after that mechanically cracked using CTM and then incubated within fine-grained fully saturated natural soil for about 4 weeks. The cracks were examined by light microscopy before and after incubation to determine the healing ratio. The data represent the utility of bio-concrete for such buildings, such as tunnels and deep foundations, where concrete components are exposed to soil conditions. Results shown that the self-healing properties for the specimens incubated in water and natural saturated soil with bacteria shown better healing properties compare to other mixes. When Compare to natural saturated soil and water incubation, maximum healing is done for soil incubated specimens.

M.V Seshagiri rao et.al.,[2] discussed about the performance of microbial concrete developed using bacillus subtilis. In this Cultured bacillus subtilis strain No JC3 is used in concrete of different grades i.e., M20, M40, M60 & M80. To determine suitable concentration of bacteria to add in concrete, firstly mortar specimens were casted using different concentrations obtained by hemo cytometer method and the Concentrations are like 10^5, 10^6 & 10^7 cells/ml. Among these concentrations mortar specimens shown higher strength for 10^5 cells/ml concentration after 28 days of curing. So, specimens were casted for all grades of concrete using with and without bacteria of concentration 10^5 cells/ml. Both mechanical and durability properties have been improved for the specimens casted using bacteria compare to control mixes.

Milan Joy et.al.,[3] discussed about the strength characteristics of self-healing concrete with fly ash. Bacillus subtilis bacteria present in soil is adopted due to its availability and resistance against varying pH conditions. Bacillus subtilis, moreover known as Grass Bacillus, is one of the Gram-positive bacteria present in soil and intestines of animals. It is a member of the Bacillus genus and has a solid, defensive spore that gives it the capacity to withstand extreme environmental conditions. The outline of the cell is usually rod-like and between 4-10 micrometers in length and 0.25 to 1.0 micrometers in diameter. This species is noticeable on the surface of the Soil. Since it possesses fermentation properties, it is used for the production of various enzymes and is used in horticulture and agriculture. In this, Cement was partially

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replaced by fly ash about 25% and bacteria concentration about $6x10^6$ cells/ml is used to prepare the concrete. Slump and compaction factor values for fresh concrete is less for conventional mix. Tests conducted on hardened concrete shown higher strength values for the mix with flyash and bacteria, and also the deflection at ultimate load for the beam specimens is less for the same mix.

Cvsr Prasad et.al.,[4] studied about the healing properties of concrete by addition of Bacillus subtilis bacteria and calcium lactate including with crushed stone dust as a complete replacement of fine aggregate. Study also includes, from ultra-sonic pulse velocity, dynamic modulus of elasticity and quality of concrete was determined at different ages. Different percentages of bacteria such as 5%, 10% and 15% of cement weight for concrete grade of M40 is added. Finally, mechanical, NDT & SEM properties were determined. The maximum strength attained at 10% bacteria in concrete with complete replacement of fine aggregate by crushed stone dust compare to conventional mix and other mixes with bacteria. Calcium carbonate formation in concrete is observed by SEM which is healing the cracks. The Ultrasonic Pulse Velocity value of Bacterial concrete Mixes increases by up to 10%; above this dosage, the effects are not favorable because hydration materials are saturated at 15% with both river sand and crushed stone sand mixtures.

I Rohini et.al.,[5] studied about the effect of bacteria subtilis on E-waste concrete. M30 grade concrete was used and coarse aggregate was partially replaced with E-waste (grinded to required size) by different percentages like 0, 5, 10, 15 & 20% and Bacteria subtilis of 1% and 2% of cement weight is also added. Before adding bacteria to concrete concentration of bacteria cells were determined. Different specimens were casted for different percentages including control mix and the results shown that the strength properties of E-Waste concrete improved by 2% by the bacterial action comparing to normal conventional concrete. The optimum percentage of bacteria to improve the properties of concrete is around 2% at 15% substitution of E-Waste.

S.S Lucas et.al.,[6] discussed about the self-healing properties in concrete with bacteria encapsulated in expanded clay. Three different types of samples were considered like control mix samples, samples incorporated with bacteria (Bacillus subtilis) and expanded clay (Aggregates replacement) and samples with expanded clay only. All the samples were pre damaged and tested for self-healing properties. From the test results obtained, it is confirmed that the replacement of aggregates with expanded clay impregnated with bacteria could effectively contribute to strength recovery in concrete and also demonstrated using EDX that the recovery has been in fact caused by the presence of calcium carbonate, the main reaction product resulting from the bacteria activity.

Sandip mondal et.al.,**[7]** studied about the properties of concrete by incorporating bacteria in it. M25 grade concrete is used and bacteria of two types were used i.e., Bacillus subtilis and bacillus cereus of concentration 10^3, 10^5 & 10^7 cells/ml. The maximum strength properties were noticed when bacillus subtilis is added in concrete. The optimum concentration of Bacillus subtilis is 10^5 cells/ml and bacillus cereus is 10^3 cells/ml in which maximum strength is obtained compare to other concentrations and control mix.

Rafat Siddique et.al.,[8] studied about properties of bacteria rice husk ash concrete. Control concrete was designed to have an output strength at 28-days is 32.8 MPa. In the control concrete, cement was partially replaced with RHA (0%, 5%, 10%, 15% and 20% by weight). Then, bacterium Bacillus aerius (B. aerius strain AKKR5 - 10^5 cells/mL) was mixed in water during making of concrete. The inclusion of bacteria in RHA-concrete results enhancement of compressive strength at all ages. However, best performance was achieved with 10% RHA wherein 28-d compressive strength was 36.1 MPa, and with bacteria, it was 40.0 MPa. Inclusion of bacterium in RHA concrete reduced its water absorption, porosity, and permeability at all ages, due to calcite precipitation, which in turn improved the properties.

Navneet chahal et.al.,[9] reported the results of an experiment carried out to evaluate the influence of Sporoscarcina pasteurii bacteria on the compressive strength and rapid chloride permeability of concrete made with and without fly ash. Cement was replaced with three percentages (10%, 20% and 30%) with fly ash by weight. Multiple cell concentrations (0, 10^3, 10^5, 10^7 cells/ml) of bacteria were used to make concrete mixtures. Tests like compressive strength, water absorption and rapid chloride permeability were conducted at 28 days of age. Test results indicated that S. Pasteurii was included in fly ash concrete increased the compressive strength, reduced the porosity and permeability of fly ash concrete. Maximum increase (22%) in compressive strength and four-times reduction in water absorption was observed with 10^5 cells/ml of bacteria. This improvement in compressive strength was due to deposition on the bacteria cell surfaces within the pores. Calcite deposition in concrete has been significantly decreased the chloride permeability of fly ash concrete by about eight times.

Kirtikanta sahoo et.al.,[10] reported the results of recycled coarse aggregates concrete using bacteria. Normal coarse aggregates were completely replaced with recycled coarse aggregates. Portland slag cement is used and bacteria of bacillus subtilis of concentration about 10^1, 10^3, 10^6 & 10^7 cells/ml is added in concrete. For the specimens consisting of bacteria of concentration about 10^7 cells/ml with 100 % replacement of Coarse aggregates by RCA shown higher strength compare to other mixes.

P Jagannathan et.al.,[11] reported the results of mechanical properties of concrete using two bacterial species. The two bacterial species are i. Bacteria pasteurii and ii. Bacteria sphaericus. Total of four mixes are prepared i.e., Control mix, Concrete mix produced by partial replacement of cement by flyash about 10%, 20% & 30%, Concrete mix produced by partial replacement of cement by flyash about 10%, 20% & 30% enriched with Bacteria pasteurii and Concrete mix produced by partial replacement of cement by flyash about 10%, 20% & 30% enriched bacteria sphaericus. By addition of flyash in concrete alone decreasing the strength of concrete but the flyash of about 10% enriched with bacteria sphaericus shown higher strength properties in compressive,

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split and flexural strength test compared to other mixes. It was concluded that Concrete made with Bacillus Pasteurii gives marginally Less Strength than Bacillus Sphaericus.

Ankit Agarwal et.al.,[12] studied about the combination of bacteria and micronized biomass silica in concrete. Many substitutes for cement like rice husk, silica fumes and fly ash have been in constant use. Among them one of the promising and emerging materials is micronized biomass silica (MBS) which is an agricultural waste product with higher silica content. It is off-white in colour and is derived from crushing rice husk but finer than the latter with high pozzolanic activity. The application of Bacillus sphaericus in concrete is capable of precipitating calcite and at the time of casting it is induced into the specimens. When these bacterial concrete specimens come in contact with the atmosphere and start precipitating calcium carbonate which covers the open spaces and hence enhance their strength and the specimens live a longer life. Bacillus sphaericus of about 10ml, 20ml & 30ml is used in concrete and also cement is partially replaced by MBS of about 8%. Different specimens are casted using bacteria with and without MBS. Bacteria of 20ml in concrete with and without MBS shown optimum results in mechanical properties like compressive and split tensile strength.

III. CONCLUSIONS

- Bacteria shall be used in concrete to obtain Self-healing property.
- The primary bacteria that tend to enhance the mechanical and durability properties of concrete is Bacillus subtilis.
- From all observations, it was concluded that, bacteria of concentration about 10^5 cells/ml shows increment in strength.
- By increasing the concentration of bacteria in concrete, strength reduces and the calcium carbonate produced after a certain percentage would not be beneficial to improve strength (hydration products) since it produces self-healing property alone.
- It is also concluded from literature studies, that the use of alternative materials (F.A/C.A. replacement) in self-healing concrete helps to further improve strength properties and also to produce self-healing property in concrete after addition of bacteria, needs proper incubation environment.

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