

Detailed Examination of Self-Healing on Cement Mortar

Aparna Ramadas, K Shobana

Abstract—Cement plays an important role as a construction binding material throughout the world. Among the different construction materials, cement stands as the most commonly used material on a construction project, from the foundation to finishes since it harmless to the human and are environmental friendly and durable. Cement is a finely ground powder and when mixing with water sets to form a hard mass. But the structure gets crack during its service life. The strength and durability of the structure is greatly influenced due to the formation of cracks and micro cracks are the main reason for structural failure. Therefore sufficient repair and maintenance is vital and unavoidable for mitigating all these problems. Recent research shows that the bacteria from the genus *Bacillus* can be used as a tool for repairing and maintaining the cracks in the structures. This project aims for experimental investigation to evaluate the influence of bacteria on self-healing of cracks formed in the mortar cubes and also on strength, permeability and durability factors of the specimen. The bacteria *Bacillus Megaterium* is used for the research and the specimens are casted and kept for curing for 28 days and compressive test was carried out. The result shows that the self healing of cracks by using bacteria by the process of bio mineralization is reliable and applicable to the field since the calcium carbonate precipitation decreases the permeability and increases the compressive strength.

Index Terms—*Bacillus Megaterium*, bacterial concrete, bio mineralization, calite precipitation, compressive strength, mortar cubes, self-healing.

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1 INTRODUCTION

Self-healing in general seeks to rectify the flaws causing cracks in the structures. An eco-friendly novel self-healing technique called biomineralization is one such approach which improves the strength and durability of concrete. Biomineralization is a novel self-healing technique and it has attracted significant attention to the several researchers. Bio mineralization is a metabolic process by the bacteria forming hard structures, surfaces or scales by combining minerals with organic compounds of some specific microorganisms. Bio mineralization involves various microorganisms, pathways and environments. It is a process which involves the precipitation of calcium carbonate (calcite) by the microorganisms. This technique is also known as microbiologically induced calcite precipitation. When the concrete is mixed with bacteria it will go into a dormant state. All the bacteria need is exposure to the air so as to activate their functions and when any cracks occur provide the necessary exposure. When the cracks form, water starts seeping through the cracks and the spores of the bacteria germinate on contact with the water and nutrients and bacteria very close proximity to the crack, starts precipitating calcite crystals and thus healing the crack. Energy Dispersive X-ray Spectroscopy can be used for documenting the influence of microbiologically induced mineral precipitation. This project paves a new way for reducing the repair and maintenance cost during the service life of the concrete and thus managing and reducing the time and cost associated with the work.

2 MATERIALS AND METHOD

2.1 Materials

Ordinary Portland cement of grade 53 is used for the investigation. The preliminary tests for cement has been carried out for various properties IS 4031-1988 and found to be confirming to various specifications of IS: 12269-1987 having specific gravity of 3.0. Standard consistency of the cement was analysed as per IS: 4031 Part 4 and was found to be 27%. Sand used was manufacturing sand having specific gravity of 2.63.

2.2 Bacterial source

The bacteria was procured from The Microbial Type Culture Collection and Gene Bank (MTCC), Chandigarh. *Bacillus Megaterium*, MTCC No: 1684 from the genus bacillus was used. *Bacillus Megaterium* is a gram positive, endospore forming, rod shaped bacteria. It is considered aerobic. It is found in soil and considered a saprophyte. *Bacillus Megaterium* has often been used in the laboratory, and is used as an industrial organism that is able to produce a variety of proteins and sources of bioremediation. *Bacillus Megaterium* is a good source of industrial proteins because it is both a desirable cloning host and produces a large variation of enzymes. The organism does not have alkaline proteases; which allows for recombinant protein synthesis. Using *Bacillus Megaterium* scientist has developed numerous proteins that are commonly used in the medical and agricultural field. General features and taxonomic position of *Bacillus Megaterium* has fascinated microbiologists since it was first described over 100 years ago. It is interesting especially because of its physiology, unusual and useful enzymes and products, and wide range of ecological habitats. It is also capable of sporulation, a simple cell differentiation cycle that serves as a model system for understanding gene regulation during temporal and mor-

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phological development. Moreover, the large size of its vegetative cells and spores make it especially amenable to morphological analysis. Although it is generally considered a soil organism, it is found in diverse environments from rice paddies to dried food, seawater, sediments, fish, normal flora, and even in bee honey. *Bacillus Megaterium* is one of the few *Bacillus* strains that has a cell width greater than 1 μm . This large size and its ability to take up di-aminopimelic acid has been exploited in several morphological studies. It has been used effectively to study cell wall synthesis as well as membrane and spore structure as reviewed recently. The kinetics of the growing vegetative cell has been determined by electron microscopy with labelled diaminopimelic acid. Temperature has a significant effect on growth and when the culture temperature increased from 15°C to 30°C, growth increased. At the temperature of 30°C it reached peak values. When the temperature was increased above 30°C, growth decreased as temperature increased. So, the optimal temperature for the growth is 30°C.

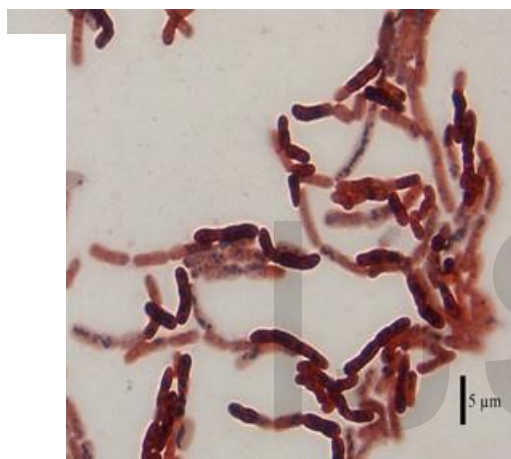


Fig:1 *Bacillus megaterium*

It secretes proteins readily, has no endotoxin in its cell wall in contrast to the Gram negatives, and is industrially proven as an organism that can give excellent yields on inexpensive substrates. Laboratories in the US, Korea, UK and Germany have documented excellent expression of foreign proteins with no degradation.

2.3 Preparation of Bacillus Megaterium

A microbiological culture, or microbial culture, is a method of multiplying microbial organisms by letting them reproduce in predetermined culture medium under controlled laboratory conditions. The bacteria obtained from MTCC culture collection center with MTCC No: 1684 was in the form of lyophilized powder. The culture was reviewed for its growth by growing in sterile Luria Berta-powder of (6.75gms) + 500ml of distilled water + peptone (3gms) + yeast extract (1.5gms) + Beef extract (1.5gms) + sodium chloride (3gms/100ml) + lyophilized powder of culture and incubated in Incubator 37°C for 24 hrs. After obtaining the growth of culture it was sub-cultured in Nutrient Agar.

2.3.1 Preparation of Nutrient Agar

Bacteriological media comes with wide range of types. Nutrient Agar is a complex medium. Nutrient Agar contains beef extract (0.3%), peptone (0.5%), and Agar (1.5%) in water. Beef

extract is prepared as dehydrated form of autolysed beef and is supplied in the form of paste. Peptone is casein (milk protein) that has been digested with the enzyme pepsin. Peptone is dehydrated and supplied as a powder. Peptone and Beef extract contains a mixture of amino acids and peptides. Beef extract also contains water soluble digest products of all other macro molecules (nucleic acids, fats, polysaccharides) as well as vitamins trace minerals. Agar is purified from red algae in which it is an accessory polysaccharide (polyalacturonic acid) of their cell walls. Agar is added to microbiological media only as a solidification agent. Agar for most purposes has no nutrient value. Agar is an excellent solidification agent because it dissolves at near boiling point solidifier at 45°C. Thus one can prepare molten (liquid) agar at 45°C, mix cells with it, and then allow it to solidify thereby trapping living cells. Below 45°C agar is a solid and remains so as the temperature is raised melting only when greater than 95°C is obtained.

2.3.2 Processing of Bacteria

In this method Bacteria will be added during casting of concrete. The amount of Bacteria added will be in the range of 10ml & 15 ml/m³ of concrete. Concrete could soon be healing its own hairline cracking. Holes and pores of wet concrete may get healed. Combined calcium with oxygen and carbon di oxide to form calcite is essential for healing tiny cracks which arrest the seepage of water. The technique of using bacterium is highly desirable because the mineral precipitation induced as a result of microbial activities, is pollution free and natural. *Bacillus megaterium* will be another partially characterized species, having the capability of precipitating calcium carbonate.

2.3 Preparation of Mortar Cubes

Mortar cubes were prepared as per IS: 4031 part 6 specifications. Cement and sand used was in the ratio of 1:3 by weight and was dry mixed. Water required was obtained by using the w/c ratio 0.45 and water is added to the mix after deducting the quantity of bacteria used for different proportion. Mortar cubes of size 70.6mm*70.6mm*70.6mm were casted with and without bacteria for comparing the results. Bacteria was added with four different proportions equivalent to the concrete cube proportion of 15ml, 30ml, 45ml, 60ml for the size 15cubic cm. The cubes were kept for curing after 24 hrs and tested for compressive strength after 28 days for both cubes with and without bacteria.

2.4 Mechanism of Bio-mineralisation

Bio-mineralization has attracted significant attention to the several researchers and presently is a research hot spot. Bio-mineralization is a metabolic process of formation of hard structures, surfaces or scales by combining minerals with organic compounds of some specific microorganisms. Bio-mineralization involves various microorganisms, pathways and environments. It is a process which involves precipitation of calcium carbonate (calcite) by microorganisms. This technique is also called microbiological induced calcite precipitation. Microbiological induced calcite precipitation technique has various applications such as consolidation of sand columns, for repair of limestone monuments and to a smaller extent for purification of water. The precipitation of calcite by bacteria forms a layer of calcite on the surface of the

specimens. This results in decrease in capillary water uptake and porosity. This biological treatment helps to improve the overall behaviour of concrete.

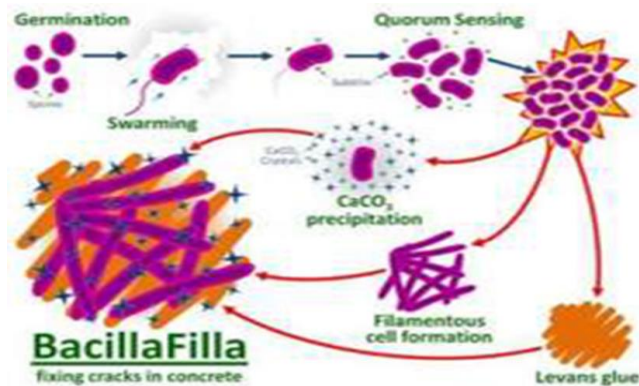


Fig: 2 Mechanism of Bio mineralization

Microbiological induced calcite precipitation technique is a novel, eco-friendly, self-healing and energy efficient technology for remediation of building materials and enhancement in the durability characteristics of concrete. This technology may bring new approaches in the construction industry.

3 CALCIUM CARBONATE PRECIPITATION

Calcium carbonate precipitation was found on the surface of the mortar cubes by the white precipitation. The capability of bacteria to precipitate calcium carbonate was studied. It clearly shows that calcite precipitation is more nearer to the surface due to the contact of atmospheric air and moisture content.



Fig: 3 Precipitation of Calcium Carbonate

4 COMPRESSIVE STRENGTH TEST

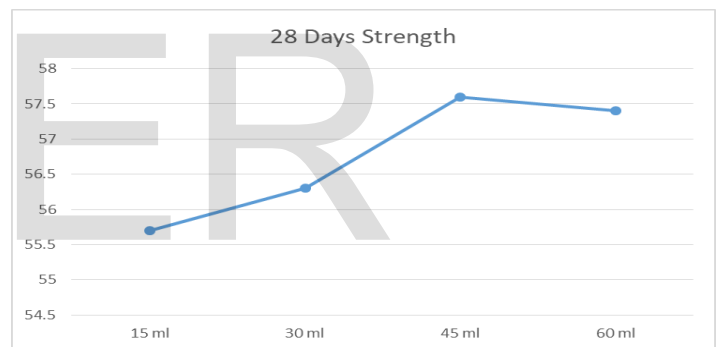
The compressive strength of mortar cubes tested in compression testing machine at 28 days for mortar cubes without bacteria and for different proportion of bacteria are tabulated

Table: 1 Compressive strength of mortar cubes without bacteria

Cubes without bacteria	28 Days Strength
Normal cube	55.4
15 ml	55.7
30 ml	56.3
45 ml	57.6
60 ml	57.4

5 ENERGY DISPERSIVE X-RAY SPECTROSCOPY RESULT

The variation of precipitation of calcium carbonate by the bacteria for different proportion in the mortar cubes was determined by using EDX.



THE GRAPH SHOWING THE VARIATIONS OF COMPRESSIVE STRENGTH IN 28 DAYS

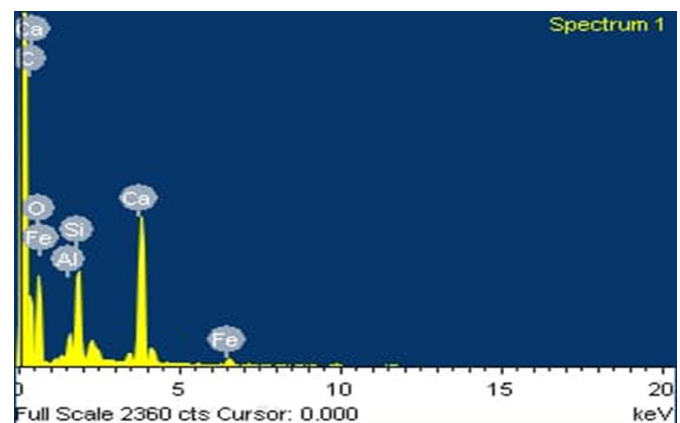


Fig:4 15ml bacteria

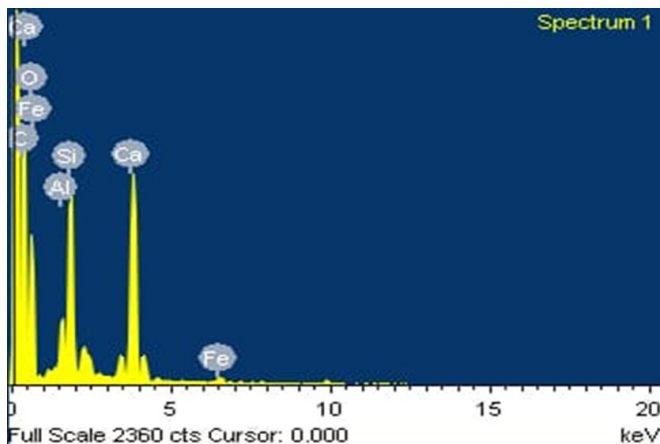


Fig:5 30ml bacteria

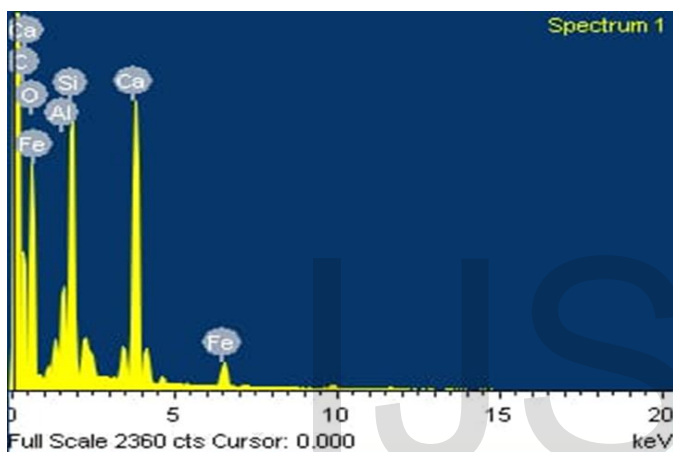


Fig:6 45ml bacteria

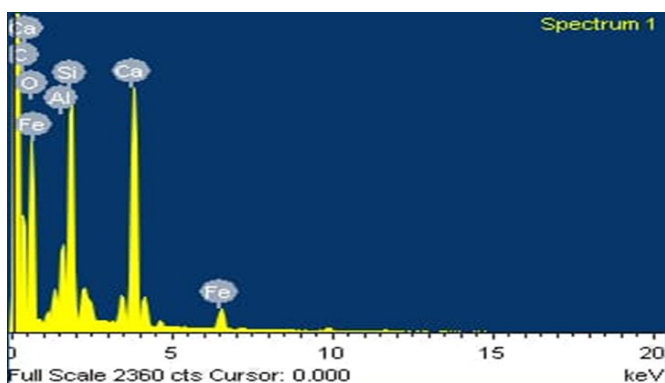


Fig:7 60ml bacteria

4 CONCLUSION

Self-healing concrete is becoming a trend over the special concrete. It is more meritorious because of its self-healing capacity than the exterior way of crack repairing. Calcium carbonate precipitate of the bacteria significantly increases the strength of concrete by filling the voids and reducing the permeability. By using the self-healing concrete the repair and maintenance cost of the structure can be reduced. From literatures it is predicted that the durability of the bacteria is more

than the life of the building. This is a very convenient and eco-friendly method. This innovation will provide durability to the building by decreasing the permeability and increasing the strength due to the precipitation of calcium carbonate by the bacteria through the process of bio mineralization. This is a starting stage of main project which will be done using special concrete in the future studies.

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