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Study of Self Healing Bacterial Concrete

Prital Gautam Kalasur, Assistant Professor, D.Y.Patil College of Enineering, Pune, India,

pritalmalgave@gmail.com

Abstract **The project gives a brief idea about increasing the strength and total durability of concrete used in the present day by introducing bacteria (Bacillus Subtilis). Bacillus Subtilis exhibits a phenomenon known as Bio Calcification as a part of its metabolic activity. It also improves the strength in concrete due to the growth of filler material within the pores of concrete. This in turn improves the strength in concrete due to growth of the filler material within the pores of the concrete mixer. A comparison study was made with concrete cubes and beams subjected to compressive and flexural strength tests with and without the bacterium. It was found that there was high increase in strength and healing of cracks subjected to loading on the concrete specimens. This project studies the formation of Bacilla Filla which is the end product of the healing process. It lists out in detail the sequence events which lead to the filling of cracks formed in the concrete. The criteria for selecting the appropriate bacteria was also studied as well as the procedure of growing and developing the cultures of Bacillus Subtilis were also undertaken.**

Keywords — Bacillus Subtilis, compressive strength, and Bio-calcification.

I. INTRODUCTION

Concrete is a strong and relatively cheap construction material and is therefore presently the most used construction material worldwide. One drawback, however, is that its massive production exerts negative effects on the environment. Another aspect of concrete is its liability to cracking, phenomenon that hampers the material's structural integrity and durability. The impact of durability-related problems on national economies can be substantial and is reflected by the sums of money spent on maintenance and repair of concrete structures.

In order to reduce the production costs, several industrial by-products such as fly ash, silica fume and blast furnace slag are nowadays commonly used as clinker (cement) replacements in concrete mixtures. Besides reducing the costs this practice also contributes to a more sustainable material as significant amounts of clinker can be saved Durability problems such as crack formation are typically tackled by manual inspection and repair, i.e. by impregnation of cracks with cement or epoxy-based or other synthetic fillers (Neville,1996).However, a promising sustainable repair methodology is currently being investigated and developed in several laboratories, i.e. technique based on the application of mineral-producing bacteria.

Self-healing concrete could solve the problem of concrete structures deteriorating well before the end of their service life. Concrete is still one of the main materials used in the construction industry, from the foundation of buildings to the structure of bridges and underground parking lots. Traditional concrete has a flaw; it tends to crack when subjected to tension.

A. GENESIS OF THE IDEA

Glue from Bacteria Can 'Knit' Cracks in Concrete

[Reported from The Times of India, Mumbai Edition dated 22nd November, 2010 page 19] London: A genetically-modified bacteria has been developed by British scientists, which can knit together cracks in concrete structures by producing a special glue .As per the research study at the Newcastle University, the microbe, can self-heal the very fine cracks to produce a mixture of calcium carbonate and bacterial glue which combine with filamentous bacteria cells to 'knit', the structure together. It can also reduce the emissions of carbon dioxide as concrete production accounts for around 5% of emissions by which this can reduce environmental impact. [PTI]

II. THEORY

The application of concrete is rapidly increasing worldwide and therefore the development of sustainable concrete is urgently needed for environmental reasons. As presently about 7% of the total anthropogenic atmospheric CO2 emission is due to cement production, mechanisms that would contribute to a longer service life of concrete structures would make the material not only more durable but also more sustainable. One such mechanism that receives increasing attention in recent years is the ability for self-repair, i.e. the autonomous healing of cracks in concrete. The starting point of the research is to find bacteria capable of surviving in an extreme alkaline environment. Cement and water have a pH value of up to 13 when mixed together, usually a hostile environment for life: most organisms die in an environment with a pH value of 10 or above. The search concentrated on microbes that thrive

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in alkaline environments which can be found in natural environments, such as alkali lakes in Russia, carbonate-rich soils in desert areas of Spain and soda lakes in Egypt. Samples of endolithic bacteria (bacteria that can live inside stones) were collected along with bacteria found in sediments in the lakes. Strains of the bacteria genus Bacillus were found to thrive in this high-alkaline environment.Self-healing materials are a class of smart materials that have the structurally incorporated ability to repair damage caused by mechanical usage over time. The inspiration comes from biological systems, which have the ability to heal after being wounded. Initiation of cracks and other types of damage on a microscopic level has been shown to change thermal, electrical, and acoustic properties, and eventually lead to total failure of the material. Usually, cracks are mended by hand, which is difficult because cracks are often hard to detect. A material (polymers, ceramics, etc.) that can intrinsically correct damages caused by normal usage could lower production costs of a number of different industrial processes through longer service life, reduction of inefficiency over time caused by degradation, as well as avoidance of costs incurred by material failure. For a material to be defined as self-healing, it is necessary that the healing process occurs without human intervention. Researchers are taking both chemically and biologically-based approaches to create concrete that heals itself. Chemical approaches typically use outside or embedded water supplies to activate dry cement grains, while biologists are looking at bacteria to fill the pores. In this study we investigated the potential of bacteria to act as self-healing agent in concrete, i.e. their ability to repair occurring cracks. A specific group of alkali-resistant spore-forming bacteria related to the genus Bacillus was selected for this purpose. Bacterial spores directly added to the cement paste mixture remained viable for a period up to 4 months. A continuous decrease in pore size diameter during cement stone setting probably limited life span of spores as pore widths decreased below 1_m, the typical size of Bacillus spores. However, as bacterial cement stone specimens appeared to produce substantially more crack-plugging minerals than control specimens, the potential application of bacterial spores as self-healing agent appears promising. Although concrete with a high self-healing (crack healing) potential is wanted, the addition of healing agents such as bacteria and/or (organic) chemical compounds to the paste may result in unwanted decrease of strength properties. Further development of this bio-concrete with significantly increased self-healing capacities could represent a new type of durable and sustainable concrete with a wide range of potential applications.

III. NESESSITY

Concrete will continue to be the most important building material for infrastructure but most concrete structures are prone to cracking. Tiny cracks on the surface of the concrete make the whole structure vulnerable because water seeps in to degrade the concrete and corrode the steel reinforcement, greatly reducing the lifespan of a structure. Concrete can withstand compressive forces very well but not tensile forces. When it is subjected to tension it starts to crack, which is why it is reinforced with steel; to withstand the tensile forces. Structures built in a high water environment, such as underground basements and marine structures, are particularly vulnerable to corrosion of steel reinforcement. Motorway bridges are also vulnerable because salts used to de-ice the roads penetrate into the cracks in the structures and can accelerate the corrosion of steel reinforcement. In many civil engineering structures tensile forces can lead to cracks and these can occur relatively soon after the structure is built. Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height.

IV. STUDY OF BACTERIA

A. Criteria of selecting the right bacteria

Bacteria should not be pathogenic. It should be a type of bacteria which is easily cultivable and can be obtained in high concentrations and high quantities as needed. It should be a durable and robust species capable of resisting extreme conditions (high temperatures, high pressure and high pH).Cement and water have a pH value of up to 13 when mixed together, usually a hostile environment for life: most organisms die in an environment with a pH value of 10 or above. It was found that the only group of bacteria that were able to survive were the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. They would become activated when the concrete starts to crack, food is available, and water seeps into the structure. This process lowers the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated. Finding a suitable food source for the bacteria that could survive in the concrete took a long time and many different nutrients were tried until it was discovered that calcium lactate was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not interfere with the setting time of the concrete

B. Formation of Bacilla-Filla

Bacterial solution is dispersed in concrete during mixing process. Then they “swim” down fine cracks in the concrete

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and produce a mixture of calcium carbonate and a bacterial glue-fiber to “knit” the concrete back together. As the bacteria grow, they produce three types of cells. One type produces crystals of calcium carbonate, one develops filament-like cells that serve as reinforcing fibers and the third produces glue that acts as a binding agent and fills the cracks.

C. Role of Bacteria in Healing Concrete

Specially selected types of the bacteria genus Bacillus, along with a calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus, are added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years. When a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria start to feed on the calcium lactate. As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralise to re-form the bone. The consumption of oxygen during the bacterial conversion of calcium lactate to limestone has an additional advantage. Oxygen is an essential element in the process of corrosion of steel and when the bacterial activity has consumed it all it increases the durability of steel reinforced concrete constructions. The two self-healing agent parts (the bacterial spores and the calcium lactate-based nutrients) are introduced to the concrete within separate expanded clay pellets 2-4 mm wide, which ensure that the agents will not be activated during the cement-mixing process. Only when cracks open up the pellets and incoming water brings the calcium lactate into contact with the bacteria do these become activated. Testing has shown that when water seeps into the concrete, the bacteria germinate and multiply quickly. They convert the nutrients into limestone within seven days in the laboratory. Outside, in lower temperatures, the process takes several weeks. Self-healing of cracks is possible only up to a certain limit. Most these materials and technology are in the research stage, which needs further study before being applied in the practical field.

V. DETAILS OF SELECTED BACTERIA

A. Characteristics of Bacillus Subtilis Subtilis

Bacillus Subtilis strain QST 713 as an active ingredient is a biological control agent for use on several minor crops to treat a variety of plant diseases and fungal pathogens including gray mold, powdery mildew, early and late blight, fire blight, scab, sour rot, bacterial spot, and walnut blight. Bacillus Subtilis is a ubiquitous bacteria commonly found in various ecological niches including soil, water and air which does not have a history of pathogenicity from contact in the environment. In addition, there are other strains of B. Subtilis which are registered as microbial pesticides. Sufficient data are available to determine that Bacillus Subtilis strain QST 713 has low toxicity to mammals and is not expected to be pathogenic in humans. Standard personal protective equipment is required to mitigate any risk to pesticide handlers and applicators. No significant risk is expected from the terrestrial ground, aerial, chemical applications or post-harvest treatment with the end-user products to birds, fish, ladybird beetles, green lacewings, honey bees, parasitic wasps, and aquatic invertebrates. The bacterium, Bacillus Subtilis, is prevalent in soils and has been found in a variety of habitats worldwide.

B. Salient Features of Bacillus Subtilis Subtilis

- Non-pathogenic and non-toxic
- Size - 0.60-0.80 µm in width and 2-3 µm in length
- Aerobic bacteria
- Highly resistant to low-high temperatures, acid and alkali conditions, hydrolytic enzymes and organic solvents.
- Spores of bacteria remains in dormant state for millions of years, without food source.
- Food source- carbon, sugar (lactose)
- Bacteria breaks at 30,000 psi (207 MPa) pressure [Concrete crushes at 4000 psi, 30MPa]
- No formation of harmful chemicals during calcite formation
- Filaments have tensile strength similar to synthetic fiber used in fiber reinforced concrete. Such ropiness is typically seen in yeast/breads due to B.Subtilis

VI. GROWTH OF BACTERIA

Primarily 12.5g of Nutrient broth (media) is added to a 500ml conical flask containing distilled water. It is then covered with a thick cotton plug and is made air tight with paper and rubber band. It is then sterilized using a cooker for about 10-20 minutes. Now the solution is free from any contaminants and the solution is clear orange in colour before the addition of the bacteria.

Later the flasks are opened up and an exactly 1ml of the bacterium is added to the sterilized flask and is kept in a shaker at a speed of 150-200 rpm overnight. After 24 hours the bacterial solution was found to be whitish yellow turbid solution. The bacterial culture was taken out and mixed in water to from a solution of volume 170 ml having cell.

VII. Concrete Mix Design

Grade:M25
Aggregate size:20mm
Target strength f ‘ck = fck + 1.65* S
For M25 Standard Deviation = 4.0

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Where,
f ‘ck = Target mean strength
fck = Characteristic compressive strength in 28 days
S = Standard Deviation

Therefore, Target strength f’ck = 25 + 1.65 x 4.0
= 25 + 6.6
= 31.6 N/mm2

Selecting Water Cement Ratio = 0.40 (assumed)

Maximum water content for Cubic Meter of Concrete for Nominal Size of Aggregate 20mm =186, clause I.S 4.6, A.S and B.S

Estimated water content Slump =10mm

Water content = 186 + 6/100 x 186 = 197 liter.

Calculating Cement Content

Assuming Water Cement Ratio = 0.4
Therefore Cement Content = 197/0.40
= 492.5Kg/m3
>320 Kg/m3
Ok

Mix Calculations (Per Unit Volume)
Volume of Concrete = 1 m3
Volume of Cement = 492.5/3.15 x 1/1000
= 0.156 m3
Volume of Water = 197/1 x 1/100
= 0.197 m3
Volume of Aggregate = a – (b-c)
= 0.647

No mineral Admixture such as Fly ash. Has been added as the reaction of Bacteria to such mineral content is both unpredictable and uncontrollable. Special admixture i.e. Bacterial culture has been added.

VIII. Method of adding Bacterial culture to Concrete

The bacterial Culture has been added to the concrete sample as a part of the water content

In the mix
5 % of the total water content is substituted with bacterial sample, as they are in liquid form and contain water
Therefore Water = (0.196 x 0.95) m3
= 0.187 m3
Bacterial Sample = (0.197 x 0.05) m3
= 0.01 m3.

Therefore Final Mix Proportion:-
Cement = 492.5 Kg/m3
Water = 0.187 m3
Bacterial Sample = 0.01 m3
Aggregate =0.647 m3

Note: These Values are for concrete cube volume 1 m3

Volume of Test sample = 150 mm x 150 mm x150 mm
= 3.375

Mix of concrete for 1 cube
Cement =1.66 Kg
Water =0.63 liter
Aggregate =0.0022 m2
Bacterial Culture = 3.375 x10*-5
=0.03375 liter
=0.034 liters per cube

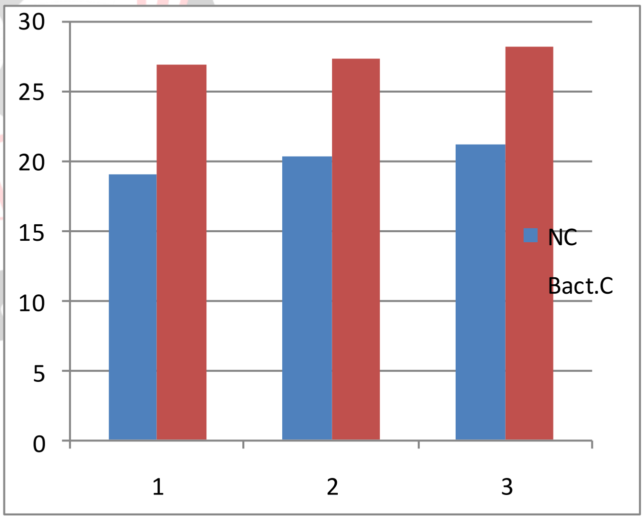
Therefore Volume of Bacterial Culture Required = No of Cubes x 0.034
= 6 x 0.034
= 0.204Liter

The tests were conducted on cubes of size: 150*150*150 mm

IX. RESULTS

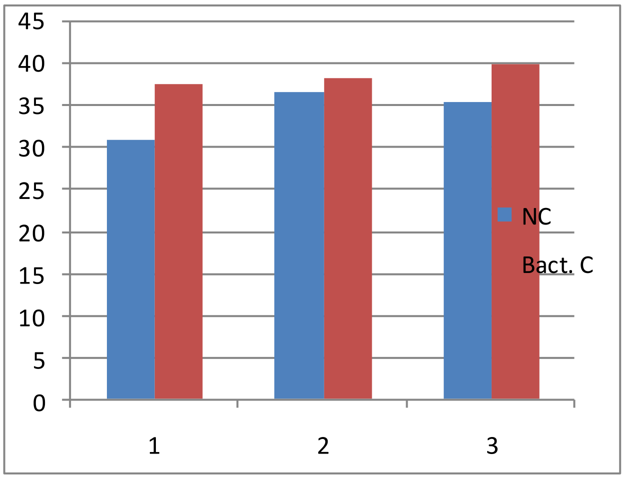
A. Compressive Strength for cubes at 07 days for Ordinary and Bacterial Concrete

Cube No.	NC (N/mm2)	Bact.C (N/mm2)	Increase in (%)
1	18.93	26.84	29.47
2	20.33	27.33	25.61
3	21.20	28.20	24.82
Mean Avg.	: 20.15	27.45	26.63



B. Compressive Strength for cubes at 28 days for Ordinary and Bacterial Concrete

Cube No.	NC (N/mm2)	Bact.C (N/mm2)	Increase in (%)
1	30.88	37.44	17.52
2	36.56	38.12	4.09
3	35.20	39.80	11.55
Mean Avg.	34.21	38.44	11.05



V. CONCLUSION

Cracks in concrete buildings, roads, and sidewalks are common and often require costly plugging.

Approximately half of the 56,000 crore spent on construction work in the UK per annum is allocated to repair and maintenance of existing structures, many of which are concrete structures. As per the estimate of the Construction Industry Development Council (CIDC), New Delhi, ` 32,000 crore is required to rebuild India's damaged concrete structures.But if concrete could detect cracking and heal itself, then there would not only be significant cost savings, but also an environmental benefit as well since concrete production accounts for significant amount of the world's carbon dioxide emissions. Self-healing of cracks is possible only up to certain limit. Most of these materials and technology are in research stage, which needs further studies before being applied in the practical field.

Self Healing Bacterial Concrete more effective than normal cement. Though study, we see that it has more advantages than disadvantages. There are at present numerous researches to produce SHC, but still the most encouraging methodology is the bio-concrete which is bacteria based because it is quite simple in comparison with other mechanism. A separate study stills needed to examine the factors like cost of construction, long term efficiency, life of bacteria and atmosphere suitability for bacteria growth.

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