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The Biological Approach to Enhance Strength in Concrete Using Bacterial and Flysah

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ABSTRACT

Concrete is the most critical element applied in public infrastructure/buildings and is often difficult to service, yet requires lengthy service periods. Recent research has shown that specific species of bacteria can actually be useful as a tool to repair cracks in already existing concrete structures. This new concrete, that is equipped to repair itself, presents a potentially enormous lengthening in service-life of public infrastructure/buildings and also considerably reduces the maintenance costs. In addition, concrete by its nature is very prone to deformations that expose its reinforcements, corroding them. Self-healing concrete offers a solution to prevent this. A novel eco friendly self healing technique called Biocalcification is one such approach on which studies were carried out to investigate the crack healing mechanism in enhancing the strength and durability of concrete. Microbiologically induced calcite precipitation (MICP), a highly impermeable calcite layer formed over the surface of an already existing concrete layer, due to microbial activities of the bacteria (Bacillus subtilis JC3) seals the cracks in the concrete structure and also has excellent resistance to corrosion.

I. INTRODUCTION:

The word concrete comes from the Latin word "Concretus" meaning compact or condensed. Concrete was used for construction in many ancient structures. Concrete is composite material composed of gravels or crushed stones (coarse aggregate), sand (fine aggregate) and hydrated cement (binder). Concrete, in the broadest sense, is any product or mass made by the use of a cementing medium. Generally, this medium is the product of reaction between hydraulic cement and water. For concrete to be good concrete it has to be satisfactory in its hardened state and also in its fresh state while being transported from the mixer and placed in the formwork. The requirements in the fresh state are that the consistence of the mix is such that the concrete can be compacted and also that the mix is cohesive enough to be transported and placed without segregation.As far as the hardened state is considered, the usual requirement is a satisfactory compressive strength. Many properties of concrete are related to its compressive strength such as durability, resistance to crack etc.

It is a well known fact that concrete structures are very susceptible to cracking which allows chemicals and water to enter and degrade the concrete, reducing the performance of the structure and also requires expensive maintenance in the form of repairs. Cracking in the surface layer of concrete mainly reduces its durability, since cracks are responsible for the transport of liquids and gases that could potentially contain deleterious substances. When micro cracks growth reaches the reinforcement, not only the concrete itself may be damaged, but also corrosion occurs in the reinforcement due to exposure to water and oxygen, and possibly CO 2 and chlorides too. Micro-cracks are therefore the main cause to structural failure. Way to circumvent costly manual maintenance and repair is to incorporate an autonomous self -healing mechanism in concrete.

CONCRETE

The global demand for concrete is massive after water, concrete is the most consumed material on Earth. Every year, the equivalent of more than 400 million dump trucks of concrete is transported to construction sites. Every man, woman, and child on the planet "consumes" around forty times their own weight in concrete per year. But concrete is vulnerable to deterioration, corrosion, and cracks, and the consequent damage and loss of strength requires immensely expensive remediation and repair.

Concrete is a composite material composed of aggregate bounded together with fluid cement which hardens over time. In its simplest form, concrete is a mixture of paste and aggregates, or rocks. The paste, composed of portland cement and water, coats the surface of the fine (small) and coarse (larger) aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

CEMENT:

Cement is a binder, a substance that sets and hardens and can bind other materials together. The word "cement" can be traced back to the Roman term opus caementicium used to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder. Cements used in construction can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to set in the presence of water. Non-hydraulic cement will not set in wet conditions or underwater; rather, it sets as it dries and reacts with carbon dioxide in the air. It can be attacked by some aggressive chemicals after setting.

II. THE BIOLOGICAL SELF-HEALING PROCESS

It is important to cover what kinds of bacteria will live in the concrete, how they work to improve the longevity of public infrastructure, what the catalyst will be that causes the chemical reaction in the bacteria, what happens to the specific kinds of specialized bacteria when exposed to the catalyst, and how they work together to not only heal cracks before they form, but also strengthen the overall structure they are incorporated into. When the bacteria are exposed to the air and the "food," the bacteria go through a chemical process that causes them to harden and fuse, filling in the crack that has formed, strengthening the structure of the concrete, and adhering to the sides of the crack to seal the damage site. This process extends the lifespan of the structure while also fixing the damage caused. The process of healing a crack can take as little as a few days [3].

When we look at the crack sizes, we generally are looking in then micro- to nano meter range to maximize the healing potential. Concrete constructions are currently designed according to set norms that allow cracks to form up to 0.2 mm wide [4][5]. Such micro cracks are generally considered acceptable, as these do not directly impair the safety and strength of a construction. Moreover, micro cracks sometimes heal themselves as many types of concrete feature a certain crack-healing capacity. Research has shown that this so called 'autonomous' healing capacity is largely related to the number of non-reacted cement particles present in the concrete matrix[7]. On crack formation, ingress water reacts with these particles, resulting in closure of micro cracks. However, because of the variability of autonomous crack healing of concrete constructions, water leakage as a result of micro crack formation in tunnel and underground structures can occur. While self-healing of 0.2 mm wide cracks occurred in 30% of the control samples, complete closure of all cracks was obtained in all bacteriabased samples. Moreover, the crack sealing capacity of the latter group was found to be extended to 0.5 mm cracks. The basic concept behind our specific version of self-healing concrete is utilizing certain types of bacteria (in the present case bacillus subtilus) and how they function to seal microscopic cracks in the concrete before they grow into larger and harder to manage cracks and breaks.

This biocalcification process involves several elements, working in unison, to complete these tasks. During the process the enzymatic hydrolysis of urea takes place forming ammonia and corbondioxide. Urease which is provided by bacteria deposits CaCo3, a highly impermeable calcite layer, over the surface of an already existing concrete layer which is relatively dense and can block cracks and thus hamper ingress of water efficiently increasing corrosion resistance and consequently increasing the strength and durability of concrete structures[8]. MICP is a complex mechanism and is a function of cell concentration, ionic strength, nutrient and pH of the medium. Modern techniques such as X-ray diffraction tests, TEM & SEM analysis can be used to quantify the study of stages of calcite deposition on the surface and in cracks [9].

HOW DOES BACTERIA REMIDIATE CRACKS

When the concrete is mixed with bacteria (bacillus subtilus), the bacteria go into a dormant state, a lot like seeds. All the bacteria need is exposure to the air to activate their functions. Any cracks that should occur provide the necessary exposure. When the cracks form, bacteria very close proximity to the crack, starts precipitating calcite crystals. When a

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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 nutrient. 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. 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. 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. Tests all show that bacteria embedded concrete has lower water and chloride permeability and higher strength regain than the surface application of bacteria. The last, but certainly not least, key component of the self-healing concrete formula is the bacteria themselves. The most promising bacteria to use for self-healing purposes are alkaliphilic (alkaliresistant) spore-forming bacteria. The bacteria, from the genus Bacillus, subtilus is adopted for present study. It is of great concern to the construction industry whether or not these bacteria are “smart” enough to know when their task is complete because of safety concerns. Bacillus Subtilus which is a soil bacterium (isolated from JNTUH soil) is harmless to humans as it is non-pathogenic microorganism.

III. LITERATURE REVIEW

Srinivasa Reddy, Achyutha Satya. Seshagiri Rao.at.el (2013)

Presented the result of Deposition of a layer of calcite crystals on the surface of the specimens resulted in a decrease of permeability of water and other liquids in concrete. The addition of Bacillus subtilis bacteria improves the hydrated structure of cement in concrete for a cell concentration of 105 cells per ml of mixing water. So, bacteria of optimum cell concentration of 105 cells per ml of mixing water was used in the investigation. The addition of Bacillus subtilis bacteria increases the compressive strength of concrete. The compressive strength is increased nearly 23% at 28 days for ordinary, standard and high grades of concrete when compared to controlled concrete. From the above proof of principle, it can be concluded that Bacillus subtilis can be safely used in crack remediation of concrete structure. Bacillus subtilis which is available in soil can be produced from laboratory which is proved to be a safe, non pathogenic and cost effective.

M.V. Seshagiri Rao, V. Srinivasa Reddy, M. Hafsa, P. Veena and P. Anusha (2013)

presented the result of an experimental investigation carried out to evaluate the mechanical properties of concrete by inducing the bacteria that is bascillus subtilis JC3 into cement mortar samples at various cell concentrations in suspension along with the mixing water. The greatest improvement in compressive strength occurs at cell concentrations of 105 cells/ml for all ages. The study showed that a 25% increase in 28 day compressive strength of cement mortar was achieved. The strength improvement is due to growth of filler material within the pores of the cement–sandmatrix. The modification in pore size distribution and total pore volume of cement–sand mortar due to such growth is also noted.

M. Manjunath, Santosh A. Kadapure, Ashwinkumar A (2014)

This paper presents the results of an experimental investigation carried out to evaluate the influence of Bacillus sphaericus bacteria on the compressive strength, split tensile strength, flexural strength, shear strength, water absorption and chloride permeability of concrete made without and with fly ash. Cement was replaced with two percentages (10 and 20) with fly ash by weight. Three different cell concentration (0, 10 3 ,10 5 ,10 7 cells/ml) of bacteria were used in making the concrete mixes. Tests were performed at the age of 28 days. Test results indicated that inclusion of B. sphaericus in fly ash concrete enhanced the compressive strength reduced the water absorption and chloride permeability of fly ash concrete. Maximum increase in compressive strength 15.47% was observed with 105 cells/ml of bacteria.

Chemistry of the Process

Microorganisms (cell surface charge is negative) draw cations including Ca2+ from the environment to deposit on the cell surface. The following equations summarize the role of bacterial cell as a nucleation site

$$Ca^{2+} + Cell \text{ --------> } Cell\text{-} Ca^{2+}$$
$$Cell\text{-} Ca^{2+} + CO_3^{2-} \text{ ----> } Cell\text{-}CaCO_3$$

The bacteria can thus act as a nucleation site which facilitates in the precipitation of calcite which can eventually plug the pores and cracks in the concrete. This microbiologically induced calcium carbonate precipitation (MICCP) comprises of a series of complex biochemical reactions. As part of metabolism, B.Subtilus produces urease, which catalyzes urea to produce CO2 and ammonia, resulting in an increase of pH in the surroundings where ions Ca 2+ and CO3 2- precipitate as CaCO3 [10].

These create calcium carbonate crystals that further expand and grow as the bacteria devour the calcium lactate food. The crystals expand until the entire gap is filled. In any place where standard concrete is currently being used, there is potential for the use of bacterial selfhealing concrete instead. The advantage of having self-healing properties is that the perpetual and expected cracking that occurs in every concrete structure due to its brittle nature can be controlled, reduced, and repaired without a human work crew. Bacterial self-healing concrete also prevents the exposure of the internal reinforcements. This form of self-healing concrete was created to continuously heal any damage done on or in the concrete structure. It was made to extend the life span of a concrete structure of any size, shape, or project and to add extra protection to the steel reinforcements from the elements. With this process, money can be saved, structures will last far longer, and the concrete industry as a whole will be turning out a far more sustainable product, effectively reducing its CO2 contribution.

IV. EXPERIMENTAL PROGRAM

The main aim of the present experimental program is to obtain specific experimental data, which helps to understand the crack healing ability of Bacterial concrete and its characteristics (Strength and Durability).This experimental program is categorized into four phases:

Phase 1: Culture and Growth of Bacillus subtilus

Phase 2: Evaluation of compressive strength enhancement in Bacterial concrete specimens

Phase 3: Evaluation of Durability enhancement in Bacterial concrete specimens

Phase 4: Microscopic analysis of CaCo3 precipitation in Bacterial concrete specimens

Materials Used The following are the details of the materials used in the investigation:

Cement

Fine Aggregate

Coarse Aggregate

Water

Microorganisms

Mix Design

V. RESULTS AND DISCUSSION

Compressive Strength of Cement Mortar

The influence of Bacillus pasteruii Bacteria on the development of compressive strength of cement mortar at ages of curing viz, 3, 7, 14, 28 days for different cell concentrations ,It is observed that the compressive strength of 1:3 controlled cement mortar specimens cured in water increases with the age of curing and the maximum strength achieved is 51.81 at the age of 28days. Mortar specimens cast using mortar mixture containing Bacillus pasteruii bacteria of 10 5 cells/ml(MOBP 5) concentration achieved maximum strength of 66.79 Mpa at the age of 28days. The increase is 16% of that of controlled cement mortar . Therefore, for further investigation bacteria with a cell concentration of 10 5 cells/ml (MOBP 5) was used in production of Bacillus Pasteruii Bacterial concrete along with the fly ash. Similarly, it is observed that the compressive strength of 1:3 controlled cement mortar specimens cured in water increases with the age of curing and the maximum strength achieved is 51.81 Mpa at the age of 28days. The increase is 10% of that of controlled cement mortar.Therefore, for further investigation bacteria with a increased cell concentration was used in production of Bacillus pasteruii Bacterial concrete with fly ash.

Compressive Strength of Concrete

In standard grade concrete the compressive strength of concrete at 7 days, 14 days, 28 days, 60 days, 2, it is observed that with the addition of bacteria the compressive strength of concrete showed significant increase by 14.92% at 28 days. The percentage of improvement in compressive strength varies at different ages. The influence of Bacillus Pasteruii , bacterial concrete along with fly ash on the development of compressive strength at different ages of curing viz, 7, 14 and 28 days , and also development of compressive strength at different ages of curing viz, 7, 14and 28, 60 days, it is observed that the compressive strength of M-40 grade controlled concrete specimens cured in water increases with the age of curing and the maximum strength achieved is 51.39Mpa at the age of 28days. Concrete specimens cast using concrete mixture containing Bacillus pasteruii bacteria of 10 5 cells/ml (COBO 5) achieved maximum strength of 63.35 Mpa the age of 28days. The Relative compressive strength increased 41% in 7 days of age and it was reduced to 25% at the age of 14 days and further it increased to52% in 28 days. The Relative compressive strength is 64% in 7 days age and it was continued to 78% in 14 days age and at the end of 28 days it reached to 100%

Split Tensile Strength

The influence of Bacillus pasteruii Bacteria's on the development of Split Tensile strength at different ages of curing viz, 7, 14 and 28 days, it is observed that the Split Tensile strength of M-20 grade controlled concrete specimens cured in water increases with the age of curing and the maximum strength achieved is 3.7 Mpa at the age of 28days..The Relative Split Tensile strength is78% in 7 days of age and it was continued to 87% in 14 days of age and at the end of 28 days it reached to 100% Similarly from Fig. 5.9, it is observed that the Split Tensile strength of M-40 grade controlled concrete specimens cured in water increases with the age of curing and the maximum strength achieved is 3.7 Mpa at the age of 28days. The Relative Split Tensile strength decreased 8% in 7 days of age and it was increased to 11% at the age of 14 days and further it increased to 16% at the age of 28 days . The Relative Split Tensile strength is77% in 7 days age and it was continued to 95% in 14 days age and at the end of 28 days it reached to 100% With the above observations, it is concluded that the both bacteria's Split Tensile strength is increasing with the age of concrete gradually. The increase is due to the bacteria's, when bacteria's used in concrete, can continuously precipitate a new highly impermeable calcite layer over the surface of the already existing concrete surface layer.

VI. CONCLUSIONS

Based on the present experimental investigations, the following conclusions are drawn: Deposition of a layer of calcite crystals on the surface of the specimens resulted in a decrease of permeability of water and other liquids in concrete. The addition of Bacillus subtilis bacteria improves the hydrated structure of cement in concrete for a cell concentration of 105 cells per ml of mixing water. So, bacteria of optimum cell concentration of 105 cells per ml of mixing water was used in the investigation. The addition of Bacillus subtilis bacteria increases the compressive strength of concrete. The compressive strength is increased nearly 23% at 28 days for ordinary, standard and high grades of concrete when compared to controlled concrete. From the durability studies, the percentage weight loss and percentage strength loss with 5% HCl and 5% H2SO4 revealed that Bacterial concrete has less weight and strength losses than the controlled concrete. Durability studies carried out in the investigation through acid attack test with 5% HCl and 5% H2SO4 revealed that bacterial concrete is more durable in terms of "Acid Durability Factor" than conventional concrete and bacterial concrete is less attacked in terms of "Acid Attack Factor" than conventional concrete. From the above proof of principle, it can be concluded that Bacillus subtilis can be safely used in crack remediation of concrete structure. Bacillus subtilis (JC3) which is available in soil can be produced from laboratory which is proved to be a safe, non pathogenic and cost effective

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