International Journal of Structural and Civil Engineering Research

ISSN 2319 – 6009 www.ijscer.com
Vol. 3, No. 4, November 2014

Research Paper

DURABILITY STUDY ON HVFA BASED BACTERIAL CONCRETE—A LITERATURE STUDY

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The aim of this research project is the development of durability of concrete in which integrated bacteria promote self-healing of cracks. Traditional concrete does usually show some self-healing capacity what is due to excess non-hydrated cement particles present in the material matrix. These particles can undergo secondary hydration by crack ingress water resulting in formation of fresh hydration products which can seal or heal smaller cracks. However, the integration of excess cement in concrete is unwanted from both an economical and environmental viewpoint. Cement is expensive and moreover, its production contributes significantly to global atmospheric CO_2 emissions. In this study durability of concrete is developed by self-healing system in which bacteria converts the metabolic organic compounds to calcite. The result has been expected that the ingress water channeled through freshly formed cracks activate present bacteria which through metabolic conversion of organic mineral-precursor compounds produce copious amounts of calcite. The self-healing capacity of this system is currently being quantified what should result in an estimate of the materials durability increase. A self-healing concrete may be beneficial for both economical and environmental reasons. The bacteria based concrete proposed here could substantially reduce maintenance, repair and premature structure degradation what not only saves money but also reduces atmospheric CO_2 emissions considerably as less cement is needed for this type of self-healing concrete.

Keywords: Bacterial concrete, High volume fly ash, Durability, Water absorption, Sorptivity

INTRODUCTION

Reinforcement corrosion is the most wide spread damage mechanism to which reinforced concrete structures are subjected when they are exposed to aggressive environments. Annual expenditure to repair corrosion damage are huge to address this problem implementation of corrosion production should be considered when there is a risk of reinforced corrosion. The corrosion of structural steel is an electrochemical process that requires the simultaneous presence of moisture and oxygen. Essentially, the iron in the steel is oxidised to produce rust, which occupies approximately six times the volume of the original material. The rate at

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which the corrosion process progresses depends on a number of factors, but principally the 'micro-climate' immediately surrounding the structure.

Fresh concrete contains high pH value (12-13) with high alkalinity. This creates a protective passive oxide layer over the steel surface, preventing it from corrosion. Gradually, with constant ingress of oxygen, water, chlorides and carbon dioxide, etc. The pH value of the concrete reduces to below 8 causing the decay of the protective layer. The Chloride ions also attack the passive layer on the metal surface exposing it to oxygen and moisture. Once the passive layer is broken the electrochemical reaction of corrosion progress unimpeded.

Self-healing property of the concrete has been introduced by the use of microorganism. Different types of Bacillus family bacteria are used for self-healing process of concrete. Bacillus pasturii bacterial properties are studied and then cultivated for the bio concrete. Bacteria of different concentration are mixed with the concrete during mixing. The bacteria inside the concrete were in deactive state. 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 mineralize to re-form the bone. The consumption of oxygen during the bacterial conversion of calcium lactate to limestone has an additional advantage. Chemical agents like nitrogen, acid etc., are essential in the process of corrosion of steel. When the crack opens the bacteria consumes oxygen to start its growth and form calcium lactate to fill the small cracks. Then the bacterial concrete increases the durability of concrete structures by protecting steel from corrosion.

PROPOSED SYSTEM

Nowadays construction industries are mainly focused in the durability aspect of the structure. To overcome this need of contractors, bacteria have been introduced in the construction industry. Bacteria added in to the concrete fills the pore spaces inside the concrete. It increases the durability of concrete. Bacterial concrete reduces the repair work which reduces the cement conception and also High Volume Fly Ash was replaced to the cement. It leads to reduce the CO_2 emission. Bacterial concrete make the environment free from pollution. Microscopic analysis is used to evaluate the growth of bacteria inside the concrete specimens.

The main objective of using High Volume Fly Ash based bacterial concrete is to increase the durability of concrete. Shrink the production of cement and emission of CO_2 to the atmosphere by increasing the usage of bacterial concrete. Various tests are carried out for finding the durability of the casted specimens.

METHODOLOGY

The methodology of the work starts from the study on the properties of the materials and the past work done from the collection of literatures for review. The bacterial properties of the fly ash to be used need to be well studied.

The materials used for casting the specimens were properly tested for finding the material properties. Depending on the material test mix design was prepared and casting has to be developed. The specimens will be cast for finding the durability of the HVFA bacterial concrete by the following methods.

- Water Absorption Test
- Sorptivity Test
- Half Cell Potentiometer Test

NEED OF BACTERIAL IN CONCRETE

Concrete is a material, which is by far the most used building material in the world. Concrete has a large load bearing capacity for compression load, but the material is weak intension. That is why steel reinforcement bars are embedded in the material to be able to build structures. The steel bars take over the load when the concrete cracks in tension. The concrete on other hand protects the steel bars for attacks from the environment and prevent corrosion to take place. However, the cracks in the concrete form a problem. Here the ingress of water and ions take place and deterioration of the structure starts with the corrosion of the steel. To increase the durability of the structure either the cracks that are formed are repaired later or in the design phase extra reinforcement is placed in the structure to ensure that the crack width stays within a certain limit. For structural reasons this extra steel has no meaning. A reliable self-healing method for concrete would lead to a new way of designing durable concrete structures, which is beneficial for national and global economy.

The "Bacterial Concrete" can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. Calcium carbonate precipitation, a widespread phenomenon among bacteria, has been investigated due to its wide range of scientific and technological implications. Bacterial concrete is used to induce $CaCO_3$ precipitation. The basic principles for this application are that the microbial urease hydrolyzes urea to produce ammonia and carbon dioxide, and the ammonia released in surroundings subsequently increases pH, leading to accumulation of insoluble $CaCO_3$. The favorable conditions do not directly exist in a concrete but have to be created. How can the right conditions be created for the bacteria not only to survive in the concrete but also to feel happy and produce as much calcite as needed to repair cracks which increases the durability of concrete.

CULTURE OF BACTERIA

Inoculation of the Bacteria

The bacteria of prepared cell concentration are then inoculated in the prepared broth medium keeping it inside the Laminar Air flow chamber. The Air flow chamber before initial use need to be cleaned thoroughly with the methylated spirit and with the UV radiation to kill the microbes inside if any. The culture was streaked on nutrient broth with an inoculating loop and the slants were incubated at 37 °C.

This ensures the quality of cultured species. Inside the Air flow chamber total backflow of atmospheric air is stopped in which the entry of harm full microbes can be stopped. The spirit lamp need to be fired such that the total temperature for growth of bacteria can be achieved while transferring it. Keen care must be taken throughout the process to ensure the quality by cleanliness. This can be achieved by using the methylated spirit as sanitizer in hands. The face mask should be used to ensure quality of cultured bacteria by avoiding the flow of microbes (if present) into the culture.

Incubation

The bacteria in inoculated broth medium are now incubated in the incubator at the temperature of about 34 °C for the period of 20 to 24 hours. This is normally done for the growth of bacteria, since the growth can only be enhanced at this temperature level.

Storage of Stock Culture

Now the inoculated broth medium is kept inside the incubator to at least 12 to 14 hours at normal room temperature to attain the cell growth of the bacteria.

Maintenance of Stock Cultures

Cultures of Bacillus Subtilus were maintained on nutrient broth culture. After 20 to 24 hours of growth, slant cultures were preserved under refrigeration (12 °C) until further use. Sub-culturing was carried out for every 15 hours. Contamination from other bacteria was checked periodically by streaking on nutrient broth plates.

Need of Fly Ash in Concrete

Nowadays there is a general trend to replace higher levels of Portland cement with fly ash in concrete. The increased pressure to use higher levels of fly ash in concrete systems is due to the following reasons.

Greater Strength: Fly ash increases in strength over time, continuing to combine with free lime.

Decreased Permeability: Increased density and long-term pozzolanic action of fly ash, which ties up free lime, results in fewer bleed channels and decreases permeability.

Increased Durability: The lower permeability of concrete with fly ash also helps keep aggressive compounds on the surface, where destructive action is lessened. Fly ash concrete is also more resistant to attack by sulfate, mild acid, and soft (lime hungry) water.

Reduced Alkali Silica Reactivity: Fly ash combines with alkalis from cement that might otherwise combine with silica from aggregates, thereby preventing destructive expansion.

Reduced Heat of Hydration: The pozzolanic reaction between fly ash and lime generates less heat, resulting in reduced thermal cracking when fly ash is used to replace a percentage of Portland cement.

Reduced Efflorescence: Fly ash chemically binds free lime and salts that can create efflorescence. The lower permeability of concrete with fly ash can help to hold efflorescence-producing compounds inside the concrete.

LITERATURE STUDY

Varenyam Achal *et al.* (2013) microbially induced calcium carbonate precipitation is a naturally occurring biological process that has various applications in remediation and restoration of range of building materials. In the present study the role of bacteria *Bacillus sp.* on the durability properties and remediation of cracks in cementitious structures were studied. ''Biocement'' induced by a Bacillus sp. lead to more than 50% reduction in the porosity of mortar specimens, while chloride permeability of concrete changed from "moderate" to "very low" as indicated by rapid chloride permeability test. The bacteria successfully healed the simulated cracks of depths including 27.2 mm in cement mortars with increase in the compressive strength as high as 40% of that of control. The results clearly showed microbially induced calcium carbonate precipitation can be applied for various building materials for remediation of cracks and enhancement of durability.

To determine the influence of MICP on microstructure both the control and MICP samples were examined under the Scanning Electron Microscope (SEM). The examination was made on the samples collected from the mortar cubes tested at 28 days. No precipitation was observed in the control samples. A clear calcite precipitation was found on the crack remediated area in the samples containing the bacterial cells. Calcite crystals grew all around the sand particles. The imprint of rod shaped bacteria was clearly visible on the crystals. It may be noted that Bacillus species have a typical rod shaped structure. SEM indicated that $CaCO_3$ crystals were precipitated on the cracks. As a result, the sand was cemented by $CaCO_3$ crystals emulating the cementation effected by cement grains in conventional concrete. The cementation resulted in increase in the compressive strength.

Jonkers (2011), a typical durability-related phenomenon in many concrete constructions is crack formation. While larger cracks hamper structural integrity, also smaller sub-millimeter sized cracks may result in durability problems as particularly connected cracks increase matrix permeability. Ingress water and chemicals can cause premature matrix degradation and corrosion of embedded steel reinforcement. As regular manual maintenance and repair of concrete constructions is costly and in some cases not at all possible, inclusion of an autonomous self healing repair mechanism would be highly beneficial as it could both reduce maintenance and increase material durability. In the present study the crack healing capacity of a specific bio-chemical additive, consisting of a mixture of viable but dormant bacteria and organic compounds packed in porous expanded clay particles, was investigated.

Microscopic techniques in combination with permeability tests revealed that complete healing of cracks occurred in bacterial concrete and only partly in control concrete. The mechanism of crack healing in bacterial concrete presumably occurs through metabolic conversion of calcium lactate to calcium carbonate what results in crack-sealing.

This bio chemically mediated process resulted in efficient sealing of sub-millimeter sized (0.15 mm width) cracks. It is expected that further development of this new type of self-healing concrete will result in a more durable and moreover sustainable concrete which will be particularly suited for applications in wet environments where reinforcement corrosion tends to impede durability of traditional concrete constructions. The outcome of this study shows that crack healing of bacterial concrete based on expanded porous clay particles loaded with bacteria and calcium lactate, i.e. an organic bio-mineral precursor compound, is much more efficient than of concrete of the same composition however with empty expanded clay particles.

Yingzi Yang *et al.* (2011) autogenous healing of early ages (3 days) ECC damaged by tensile preloading was investigated after exposure to different conditioning regimes: water/air cycles, water/high temperature air cycles, 90%RH/air cycles, and submersion in water. Resonant frequency measurements and uniaxial tensile tests were used to assess the rate and extent of self-healing. The test results show that ECC, tailored for high tensile ductility up to several percent and with self-controlled crack width below 60 ìm, experiences autogenous healing under environmental exposures in the presence of water.

However, the recovery for these early age specimens is not as efficient as the recovery for more mature specimen, for the same amount of pre-damage and exposure to the same environment. Even so, the self-healing for these early age specimens demonstrates high robustness when the preloading strain is limited to 0.3%. This conclusion is supported by the evidence of resonant frequency and stiffness recovery of the healed ECC materials.

The study presents the findings of an investigation into the autogenous healing of ECC subjected to different environmental exposure regimes, after deliberate damage by preloading in direct tension at 3 days of age. The inherent tight crack width of ECC, less than 60 μm, leads ECC to display robust self-healing properties at early ages with appropriate environmental exposure. Self-healed ECC shows substantial RF recovery as well as recovery of uniaxial tensile stiffness.

The self-healing of micro cracks in ECC is expected to overcome the problem of early age cracking in high performance concrete materials for infrastructures exposed to water, e.g., transportation infrastructure such as roadways and bridges or in water-retaining structures. Thus self-healing ECC should maintain stiffness, strength and ductility even when subjected to damaging loads at an early age, especially when the damage level is limited to below 0.3%.

Willem De Muynck *et al.* (2008) surface treatments play an important role in the protection of construction materials from the ingress of water and other deleterious substances. Due to the negative side-effects of some of the conventional techniques, bacterial induced carbonate mineralization has been proposed as a novel and environmental friendly strategy for the protection of stone and mortar. This paper reports the effects of bacterial $CaCO_3$ precipitation on parameters affecting the durability of concrete and mortar. Pure and mixed cultures of ureolytic bacteria were compared for their effectiveness in relation to conventional surface treatments. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas.

Bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surfaces. The type of bacterial culture and medium composition had a profound impact on $CaCO_3$ crystal morphology. The use of pure cultures resulted in a more pronounced decrease in uptake of water, respectively less pronounced change in the chromatic aspect, compared to the use of mixed ureolytic cultures as a paste.

The results obtained with cultures of the species Bacillus sphaericus were comparable to the ones obtained with conventional water repellents. Deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary suction and a decrease in gas permeability. Treatment with bacteria resulted in a limited change of the chromatic aspect of mortar and concrete surfaces. The type of bacterial culture and medium composition had a profound impact on $CaCO_3$ crystal morphology. The use of pure cultures resulted in a more pronounced decrease in uptake of water, respectively, less pronounced change in the chromatic aspect, compared to the use of mixed ureolytic cultures as a paste.

MATERIALS AND METHODS

Materials and Mixing

Ordinary Portland cement of 53 grade with standard consistency of 30% and specific gravity of 3.15. Fly ash of class F with specific gravity of 2.31 will be used. Fine aggregate confirming to IS: 383-1970 with 2.42 specific gravity and coarse aggregate of 20 mm size, 0.55% water absorption and specific gravity of 2.78 will be used for preparation of concrete specimens. Micro organism of Bacillus subtilus is cultured and added to the water during mixing of concrete in three different concentrations like 10^5 cells/liter, 10^6 cells/liter and 10^7 cells/liter. M40 grade mix will be used for the specimens and 40% of cement is replaced by Fly ash.

Methods of Testing

Convention concrete specimens with HVFA will be prepared for determining the mechanical properties and durability of the concrete. Bacterial concrete with different concentration will be prepared for finding the mechanical properties and durability of the concrete.

Mechanical Properties

Mechanical properties like compression test, split tensile strength and flexural strength will be carried out. Cube specimens of size 150 mm x 150 mm x 150 mm, Cylinder specimens of 150 mm diameter and 300 heights and prism of size 500 mm x 100 mm x 100 mm will be casted for finding the mechanical properties like compression, split tensile and flexural strength respectively.

Durability Tests

Standard cubes of size 150 mm x 150 mm x 150 mm will be casted for water absorption test and sorptivity test. The beam element of size 1.0 m x 0.19 m x 0.19 m will be prepared finding the corrosion of the steel reinforcements embedded in the concrete.

EXPECTED RESULTS

Microorganism inside the concrete fills the spores inside the specimens. Reduction of pore sizes increases the mechanical strength of the concrete. Depending on the concentration strength also increased gradually. Bacteria inside the concrete fill the air voids so water absorption percentage, Sorptivity coefficient value will be reduced and it increases the durability of the concrete.

CONCLUSION

The above said test is to be conducted in phase-II project work.

Here, we are expecting the durability of the concrete will increase with the involvement of bacteria (in form of liquid) and flyash. Specimens are now ready for the further process of durability test.

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