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CORROSION PREVENTION OF REINFORCED CONCRETE WITH MICP

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***Abstract-** This paper investigates the properties of micro-induced calcite precipitation with regard to, surface finish and sealing cracks in cementitious materials. Mortar and concrete are most widely used building materials all over the world as they are cheap, easily available and convenient to cast. But crack in these materials is a common phenomenon during its service life due to many reasons, if unattended timely, will result in long-term structural deterioration with high level of risk maintenance cost. The corrosion of reinforcement (steel bar) in concrete structures is one of the most frequent reasons for civil infrastructure failure. Recently, there has been growing interest in microbial self-healing process due to its potential in long lasting, efficient and environment-friendly crack repair of concrete. Bacillus, a common soil bacterium can continuously precipitate calcium carbonate (calcite) under favorable conditions. It is called microbiologically induced calcite precipitation (MICP). This Phenomenon comes under a broader category of science called "bio-mineralization".*

***Keywords-** cementitious material, deterioration, corrosion of steel, self-healing, Bacillus, MICP, bio-mineralization*

1. INTRODUCTION

Concrete which forms major component in the construction as it is cheap, easily available and convenient to cast. But these materials also have some drawbacks which are weak in tension so, it cracks under sustained loading and due to aggressive environmental agents, which ultimately reduces the life of the structure which are built using the Concrete. Steel corrosion occurs because of moisture penetration resulting from a variety of factors. The lack of a cost-effective, eco-friendly repair method is a cause of concern: 'In the United States of America, for instance, the annual direct costs for maintenance and repair of concrete highway bridges due to corrosion of the reinforcement is 4 billion dollars' [1]. Currently, Synthetic material like epoxies are used for remediation. But they are not compatible, costly, harmful to the environment, reduce aesthetic appearance and need constant maintenance. Therefor bacterial induced Calcium Carbonate (Calcite) precipitation has been proposed as an alternative and environment friendly crack remediation and hence improvement of strength of building materials. Due to its inherent ability to precipitate calcite continuously bacterial concrete can be called as a "Smart Bio Material" [2]. This Technique is highly desirable because the Calcite precipitation induced as a result of microbial activities is free from any pollution and natural and it can also be used to increase the compressive strength and stiffness of cracked concrete specimens. In Research it is found that microbial Calcium Carbonate precipitation has ability to heal cracks of construction materials and also led to many applications like crack remediation of concrete, restoration of historical monuments and other such applications. If natural Calcium Carbonate precipitation can be used as a repair agent, lower cost materials can be maintained to an acceptable performance standard. Cracks under 0.05mm are not deemed problematic as concrete can repair itself through swelling of the cement paste, hydration of the remaining un-hydrated cement, precipitation of calcium carbonate ($CaCO_3$) crystals, and crack filling by impurities in water or by debris from the crack surface [3]. Four different factors regulate MICP performance, which include: (i) concentration of soluble calcium, (ii) concentration of carbonate, (iii) pH, and (iv) availability of nucleation sites for the formation of calcium carbonate crystal [4]. The bacteria are Bacillus alkali-nitrulicus, an alkali-resistant soil bacterium, psychrophilic bacterium, Bacillus pasteurii (**Sporosarcina pasteurii** formerly known as **Bacillus pasteurii** from older taxonomies) is added, which can survey at high pH of 9 to 13 and at the temperature range of 10 to 40 degree centigrade [5].

2. CORROSION OF EMBEDDED METALS

Corrosion of reinforcing steel and other embedded metals is the main cause of deterioration in concrete. When steel corrodes in a structure, the resulting rust occupies a greater volume than the steel. This expansion or volumetric change creates tensile stresses in the concrete, which can eventually cause cracking and spalling (Figs. 1). Steel corrodes because it is not found in nature. Rather, iron ore is melt down and refined to produce steel. The yield steps that change iron ore into steel add energy to the metal. Steel, like most metals except gold and platinum, is thermodynamically unstable under normal atmospheric conditions and will release energy and revert back to its natural state—iron oxide, or rust. This process is called corrosion.

Fig. 1. Corrosion of reinforcing steel is the most common cause of concrete deterioration. (46080)

Corrosion in steel is an electrochemical process involving the flow of charges (electrons and ions). Fig. 2 shows a corroding steel bar embedded in concrete. At active sites on the steel bar, called anodes, atom of iron loses electrons and move into the surrounding concrete as ferrous ions. This process is called a half-cell oxidation reaction, or the anodic reaction.

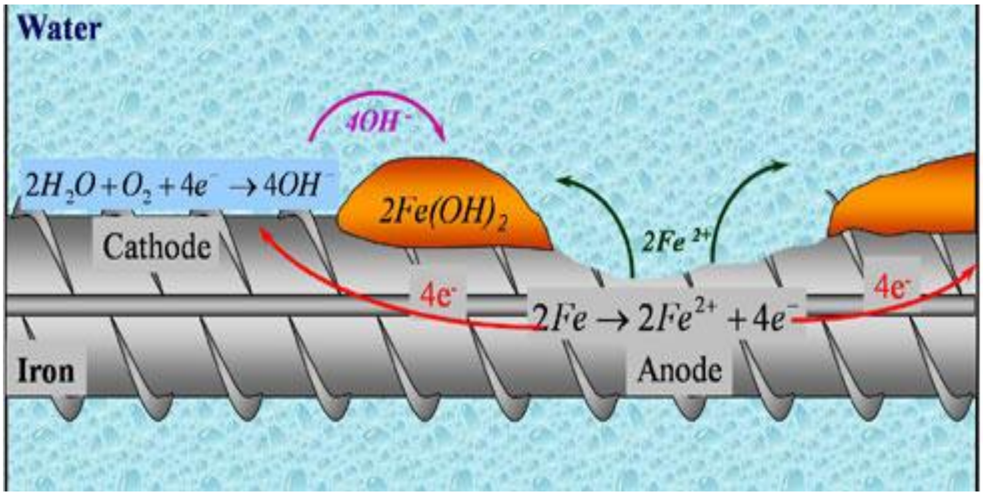

Fig. 2. When reinforcing steel corrodes, electrons flow through the bar and ions flow through the concrete [6].

The stiffness and shear capacity of the reinforced concrete decrease as the corrosion level increases. However, the decrease of the stiffness is neglectable when the applied load is relatively low. It is only when the applied load exceeds 20-30% of its ultimate load, the stiffness loss caused due to corrosion becomes considerable. As the corrosion level becomes rigid, shear failure mode of the beams may change from concrete crushing to stirrup failure. This is attributed to the cross-section loss of stirrup bars, which becomes severer as the corrosion level increases.

3. BACTERIA

Bacteria are abundant, incredibly diverse and conduct precipitation of mineral carbonates across a spectrum of natural environments [7]. The majority of bacteria are either spheres and known as cocci or rod shaped and referred to as bacilli [7]. In nature, it is common for microbial mineral plugging to occur in porous media. Bio-calcification or microbiologically induced calcite precipitation (MICP) is a phenomenon concerning the urease enzyme [8]. Microbial $CaCO_3$ has wide scope, as it has a varied range of environmentally friendly applications. It can consolidate damaged materials, especially ones bearing cracks [9]. MCIP is a natural phenomenon which is associated with a range of bacteria species given the right conditions, in particular, an alkaline environment rich in $Ca2^+$ ions [10]. The calcite deposition is able to consolidate media and potentially reduce moisture access.

4. PREPARATION OF BACTERIAL CONCRETE

Bacterial concrete is a product that will produce limestone to fill cracks that appear on the surface of concrete structures. *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 inactive within the concrete for up to 200 years.

Currently, two methods are being studied for Preparation of Bacterial Concrete: -

1. BY DIRECT APPLICATION

In the direct application method, bacterial spores and calcium lactate is added into concrete directly when mixing of concrete is done.

The use of this bacteria and calcium lactate doesn't change the normal properties of concrete.

When cracks are occurred in the structure due to obvious reasons.

The bacteria are exposed to climatic changes.

When water comes in contact with this bacteria, they germinate and feed on calcium lactate and produces limestone.

2. BY ENCAPSULATION IN LIGHTWEIGHT CONCRETE

By encapsulation method the bacteria and its food i.e. calcium lactate, are placed inside treated clay pellets and concrete is prepared.

About 6% of the clay pellets are added for making bacterial concrete.

When concrete structures are made with bacterial concrete, when the crack occurs in the structure and clay pellets are broken and the bacteria germinate and eat down the calcium lactate and produce limestone, which hardens and thus sealing the crack.

5. PROCESS OF FIXING CRACKS IN CONCRETE BY BACTERIA

When a concrete structure is damaged or deteriorate and water starts to seep through the cracks that occur 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 consumes oxygen and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby filling the cracks. It imitates the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralize to re-form the bone. When oxygen feeds by bacteria 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 make sure that the agents will inactivate during the cement-mixing process. Only when cracks open up the pellets and seeping water brings the calcium lactate into contact with the bacteria do these become activated. Tests has shown that when water enters into the concrete, the bacteria germinate and multiply quickly. The nutrients convert into limestone within seven days in the laboratory. Outside, at low temperature, the process takes several weeks.

6. DICUSSION AND FUTURE CHALLENGES

Weathering action is a major cause of disintegration of reinforcement concrete and the main purpose of MICP technique is microbes can improve the durability of reinforced concrete and the bacteria in concrete is having properties of self-healing agent. The urease enzyme catalyzes the hydrolysis of urea to carbon dioxide, resulting carbonate concentration layer formed by bacteria due to which increase the permeability of the specimen along with it increasing compressive strength also point out. The main future challenge is of designing self-healing concrete by biological process which has not been completely in understood till now. Many bacteria which are isolated from nature are useful in self-healing concrete but the challenges are 1. bacteria cannot resist harsh condition like high pH, 2.low level of water, 3. high temperature and etc. So that the bacteria which can complete above challenges are required. Although, in these types of bacteria Fungi is very important which mechanism is filling cracks or optimum growing condition. But till now it is not in working condition.

CONCLUSION

In microbial concrete technology it has been seen that it is better than many conventional technologies because of self-healing ability, eco-friendly in nature, and increase the durability of various building materials. Work of various researchers has improved our understanding in biotechnological applications on building materials. Enhanced Compressive strength, reduction in permeability, water absorption, protection from corrosion in reinforced has been seen in various cementitious and stone material.

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