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POTENTIAL OF BACTERIA AS A SELF-HEATING AGENT IN CONCRETE

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ABSTRACT

Concrete is used world wide as a construction material because of its several properties. The main problem with concrete is that, it has low tensile strength which results in development of cracks. These cracks thereafter allow chemicals and water to enter in the surface of the concrete and degrade the concrete, reducing the performance of the structure and also require expensive maintenance in the form of repairs. Micro cracks are therefore the main cause of structural failure as they damage concrete and reinforcement due to exposure to water and oxygen and possibly CO2 and chlorides. In this paper the applicability of specifically calcite minerals precipitating bacteria for concrete repair and plugging of pores and cracks in concrete has been recently investigated. Also the possibility of using bacteria as a sustainable and concrete embedded self healing agent was studied and results from ongoing studies are discussed.

Keywords: *Bacterial concrete, self healing process.*

I. INTRODUCTION

Concrete is presently the most used construction material worldwide because it is a strong and relatively cheap construction material. Though concrete has a massive production, it exerts a negative effect on the environment. It is estimated that about 7% of global anthropogenic CO_2 is released from the cements production industries [1]. As concrete is considered as one of the most important construction materials therefore advancement in concrete technology is in its strength improvement and its enhancement in durability, using pollution-free and natural methods gain popularity. This needs to be taken care of at the design stage itself [2]. Autogenous crack-healing capacity of concrete has been recognized in number of studies recently. Mainly micro cracks with width typically in the range of 0.05 to 1.0 mm have been to become completely sealed particularly under repetitive dry/wet cycles. The main concern of the present research therefore was to develop a type of sustainable self-healing concrete using a sustainable self-healing agent. It was reported that the effect of bio-deposition enhances the durability of cement mortar/concrete specimen. It was also observed that deposition of $CaCO_3$ crystals reduces the water absorption of the sample depending on the inherent porosity of the specimen leading to a decrease in the carbonation rate by about 25-30% [2]. Another aspects of concrete is its liability to cracking, a phenomenon that restrains the material's structural integrity and durability. The effects of durability problems reflect so much on the money spent for maintenance and repair works of concrete structure [1]. Cracking of concrete is a common phenomenon and without immediate and proper treatments, cracks in concrete structure tend to expand further which eventually require costly repair. Though it is possible to minimize the extent of cracking by available modern techniques includes use of epoxy resins, epoxy mortar and other synthetic mixtures. Use of bacterial in concrete remediation is an orthodox concept in ongoing concrete research. It is however, a new approach to an old idea that a microbial mineral deposit constantly occurs in natural environment. The long term goal is to understand the significance and behavior of micro-organisms in concrete structures [3]. Therefore bacterially induced calcium carbonate precipitation has been proposed as an alternative and environmental friendly crack repair technique [4]. Durability problems such as crack formation are typically handled by manual inspection and repair, i.e. by impregnation of cracks with cement or epoxy-based or other synthetic fillers. An integrated healing agent will save manual inspection and repair and moreover enhances the structure's durability. Addition to such an agent to the concrete mixture would save both money and environment [2].

II. Bacteria - A self healing agent

Bacteria used as self healing agent added to concrete mix in suspension state must meet certain criteria. As concrete is a highly alkaline building material, so bacteria should be able to survive in this high alkaline environment for long durations

and be able to form spores (highly resistant structures) withstanding mechanical forces during concrete mixing. In the concrete technology laboratory, a bacterial concrete mix is prepared using alkali-resistant soil bacteria Bacillus subtilis JC3 , along with nutrients from which the bacteria could potentially produce calcite based bio-minerals. Then the 28 days cured bacterial specimens are examined visually by Scanning Electron Microscope to establish evidence for the precipitation of calcite crystals in concrete. It was found that strains of the bacteria genus Bacillus were found to flourish in this high-alkaline environment. Such gram positive bacteria have extremely thick outer cell membrane that enables them to remain viable until a suitable environment is available to grow. They would become active when the cracks form on concrete surface allowing water to ingress into the structure. This phenomenon results in reduction of pH value of the concrete environment where the bacteria incorporated become activated. Calcite crystals are produced if peptone based nutrients supplied along with bacteria in suspension. The results show that this biomineralisation process will not interfere with the setting time of the concrete. The most expensive ingredient in developing bacterial concrete is nutrients. So the cost of bacteria based self healing sustainable concrete can be reduced by any inexpensive alternative for laboratory growth media. Only factor need to be checked is the effect of nutrients media on the setting time of cement. Various types of bacteria used are Bacillus Pasteurii, Bacillue Sphaericus, Bacillus Subtilis, Sporosarcina Pasteurii etc.

III. Mechanism of Self-healing Process Using Bacteria

For effective crack sealing the integrity of cement sand matrix should not be disturbed by addition of both bacteria and nutrients. The principle behind bacterial crack healing mechanism is that the bacteria should able to transform soluble organic nutrients into insoluble inorganic calcite crystals which seals the cracks. The integrity of cement sand matrix should not be disturbed by both bacteria and nutrients incorporated into concrete and also should not negatively affect other important fresh and hardened properties of concrete. Only spore-forming gram positive strain bacteria can survive in high pH environment of concrete sustaining various stresses. It was noted that when bacteria is added directly to the concrete mix in suspension, their life-time is limited due to two reasons; one is continuing cement hydration resulting in reduction of cement sand matrix pore-diameter and other is due to insufficient nutrients to precipitate calcite crystals. However, a fresh and new method of protecting the bacterial spores by immobilization before addition to the concrete mixture appeared to substantially prolong their life-time.

IV. The Working Principle of Self-healing Process

In concrete the cracks up to 0.2 mm wide are acceptable as these do not directly influence the safety and strength of the concrete. In concrete autogeneous healing happens due to hydration of non-reacted cement particles present in the concrete matrix when comes in contact with ingress water resulting in closure of micro cracks. However, micro cracks can still occur because of the variability of autonomous crack healing of concrete. Cracks up to 0.5mm width were found to be completely healed by the inbuilt bacteria-based self-healing process. On the surface of control concrete, calcium carbonate will be formed in the concrete matrix according to the following reaction:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

The calcium carbonate ($CaCO_3$) production in this case is due to the limited amount of CO_2 present. As calcium hydroxide ($Ca(OH)_2$) is a soluble mineral gets dissolved in ingress water and diffuse out of the crack in the form of leaching. The self healing process in bacterial concrete is much more efficient due to the active metabolic conversion of calcium nutrients by the bacteria present in concrete:

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O$$

This process results in efficient bio based crack sealing technique. Ureolytic bacteria such as Bacillus subtilis JC3 can able to precipitate $CaCO_3$ in the high alkaline environment by converting urea into ammonium and carbonate. The ammonia degradation of urea results in increase of pH and promotes the microbial deposition of carbonate as calcite crystals in a calcium rich environment along with maintaining the pH of concrete. These precipitated crystals thus seal the cracks.

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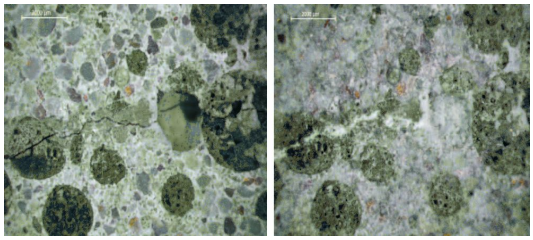

Fig. Crack filling by self-healing process using bacteria.

The factors such as the concentration of dissolved inorganic carbon in the form of available nutrients, the pH of the environment, availability of calcium ions and the presence of nucleation sites helps to determine the microbial precipitation of calcite crystals.

V. Effect Of Healing Agent on Specimen Strength

As incorporation of healing agents to concrete may have undesirable negative effects on material properties, development of compressive strength of control specimen without additions as well as specimen with bacteria or organic compound additions was investigated. Incorporation of a high number of bacteria appears to have a gently negative effect on compressive strength development as bacterial test specimen appeared almost 10% weaker then control specimen. Effect of organic compound incorporation on development of strength appeared however strongly dependent on compound identity.

VI. Conclusions

In conclusion, the positive potential of microbial induced calcite precipitation that has been demonstrated in present study offers an interesting concept to enhance material properties such as compressive strength and crack remediation in building materials. Also this technology is proved to be better than many conventional technologies because of its eco-friendly nature, self-healing ability and increase in durability of various building material. Cementation by this method is very easy and convenient. As further study is required to get a more benefit from this material as this superior and smart material has various limitation.

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