BACTERIA INDUCED SELF-HEALING CONCRETE-A REVIEW

Baban Kumar[1]

1. Dr B R Ambedkar National Institute of Technology Jalandhar, India

ABSTRACT. Concrete is an extensively used building material used for construction works. It is well known that one of the weaknesses of concrete is its vulnerability to cracking. Cracks may occur when concrete is in a plastic state or after it has completely hardened. Micro cracks in concrete also affect durability by allowing ingress of corrosive substances into the concrete matrix, which lead to corrosion of steel and loss in tensile strength. Such occurrence may lead to more adverse problems such as spalling and even premature structural failure. Repair and maintenance of concrete structures are labour and capital intensive. It is difficult to access the degree of damage after the construction is completed. Self-healing is a possible solution. There are many approaches of self-healing such as Autogenous and Autonomous Self-Healing. Bacteria-induced mineral precipitation is an environmentally friendly technology to enhance the self-healing ability of concrete cracks. The objective of this paper was to report the effects of bacteria-based additives on the properties of concrete such as compressive strength, split tensile strength and flexural strength and a clear comparison can be made for strengths of different specimens of bio concrete using different bacteria and conventional concrete. Moreover, the water permeability and chloride penetration resistance properties of concrete specimens were investigated. Self-healing is also confirmed by SEM photographs and XRD analysis.

Keywords: Self-Healing, Bacteria, Durability, Repair and Maintenance.

Mr Baban Kumar is a PG Scholar of Civil Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India.

INTRODUCTION

Concrete, an extensively used material in construction work, is also a major contributor to depletion of natural resource and environmental pollution through the production of its major component-cement [1, 2]. It is strong enough to resist compressive load but prone to cracking due to weak in tension which ultimately reduce the life of structure. Hence, any effort to improve the life span of structure will indirectly improve the sustainability of the environment [2, 9]. Cracks in concrete lead to ingress of chemicals in to concrete structure resulting in lower strength and durability [5, 20, 24]. To increase the durability of the structure either cracks are repaired which is expensive or provide extra reinforcement to ensure the cracks width stays within certain limit. Only for durability reason, this extra steel is not desirable. One way to increase the durability of structure and reduce such extra cost is to use self-healing concrete. Self- healing of concrete is any process by the material itself involving the recovery and hence improvement of performance after an earlier action that had reduce the performance of material [6]. In general, there are two main approach of self-healing [29] are Autogenous and autonomous self-healing.

Approaches to Self-Healing

Autogenous self-healing depend on the composition of concrete and is unblemished by hydration reaction of cementitious products within the concrete matrix. In most of the conventional concrete matrix, 15-25% of the cement is left un-hydrated. If cracking of the concrete occurs, un-hydrated cement grains may exposed to moisture penetrating the crack. In that case the hydration process may start again ad hydration products may fill up and heal the crack. This inherent self-healing mechanism is known since long and known as autogenous healing. It is primarily effective for very narrow cracks [26, 27, 28], but unable to heal wide cracks [15]. It is more effective in fresh concrete as constant supply of water is required [29].

Autonomous self-healing depicts the induction of engineered unorthodox supplements into the concrete matrix to enhance the self-healing ability [8, 23]. Bacteria spores are incorporated to intermediate the self-healing by precipitation of calcium carbonate but they did not survive for a long time due to alkaline medium and shrinkage of pores [9, 10, 12]. Furthermore bacterial spores are capsulated and incorporated in concrete leads to increase in lifespan of bacterial healing agent [11]. It can heal up to crack width of 0.5 mm [30]. When rainwater or atmospheric moisture seeping into cracks, the inactive bacteria become active [31].They reproduce and germinate in the calcium lactate and combine with carbonate ions to form insoluble calcium carbonate which fills the cracks [23].

Mechanism of Self-Healing

The process of using microbes in bio concrete is known as Microbial Induced Calcium Carbonate Precipitation (MICCP) or Bio-mineralization [14]. After activation, bacteria undergo some metabolic process such as sulphate reduction, photosynthesis and urea hydrolysis results in calcium carbonate as their by product. Various bacteria can precipitate calcium carbonate such as

Bacillus Pasteurii, Bacillus Subtilis, Bacillus Sphaericus, Bacillus Cohnii, Bacillus Pseudofirmus, Bacillus Halodurans etc. in both normal and laboratory conditions. Precipitation is mainly governed by pH value, Calcium concentration, DIC (Dissolved Inorganic Carbon) concentration, Nucleation sites [13]. For accomplishment of self-healing phenomenon, it is most important that the bacteria should be able to convert the organic nutrients into insoluble inorganic calcite crystal which fills the cracks. Self-healing agent consists of bacteria which act as catalyst and calcium calcite that will converted into calcium carbonate [7].

Suitability of self-healing concrete in India

The climate of India is diverse from region to region due to its topography and having a wide range of change in temperature from mountains, plains, forests to beaches. Many cities like New Delhi, Patna, Lucknow, Jalandhar etc. encountering temperature changes from very warm climate in April to mid-June to very cold climate between November and February. Extreme climate can deteriorate and tend to cracks in concrete structure which may ultimately reduce the life span of structure. Bio concrete may be the best alternative to resist these extreme climatic conditions. In India like developing concrete, infrastructure development can play a vital role so bio concrete can be used in construction work. Bacterial induced concrete is environmental friendly carbonate precipitation self-healing technique and it is highly desirable in underground and offshore structure etc. where minute crack is detrimental [24]. Apart from this bio concrete can be used for constructing irrigation structure.

Advantages and disadvantages of Bio Concrete [4]:

Advantages

- The use of bio concrete significantly influences the strength of concrete.
- It has lower permeability than conventional concrete.
- It offers great resistance to freeze-thaw attacks.
- Remedying of cracks can be done efficiently.
- The chances of corrosion in reinforcement are reduced.
- Maintenance cost of this concrete is low.

Disadvantages

- Design of bacterial concrete is not mentioned in IS codes or any other codes.
- Cost of this concrete is comparatively higher than conventional concrete i.e. about 7-28% more than conventional concrete.
- The investigations involved in calcite precipitation are costly.
- Bacteria that grow in concrete are not good for human health and atmosphere and hence its usage should be limited to the structure.

MECHANICAL PROPERTIES OF CONCRETE

Different type of bacteria is embedded in to concrete matrix to analyse the effectiveness of self-healing phenomenon of concrete. Different mechanical properties test have been carried out to check the performance of bio concrete. Incorporation of different microorganisms to observe the strength and reported an increase in compressive strength of concrete by 6.42% and 9.16% for 7 days and 28 days respectively using Baccilus Subtilisfor and by using Baccilus Pasteurii, they observed 29.99% and 29.97% increase in compressive strength of concrete for 7 days and 28 days respectively [32]. They used another bacteria named Baccilus Sphaericus and got highest increment as 65.93% and 52.42% for 7 days and 28 days respectively compared to conventional concrete where as another group of authors investigated the compressive strength of cement mortar, by using Bacillus cereus and Bacillus pasteurii in differentcell concentrations on cement mortar, and observe 38% and 28% increment respectively [17].

There is reduction in cylindrical compressive strength by 9% and cubic compressive strength shows no noticeable change when cracks are induced in cube and cylinder subjecting them to compressive loading and bioremediation of 28 days [22] while another investigated the compressive strength by blending Bacillus Subtilis and observe 10% increase in compressive strength and improvement in porosity due to inclusion of bacteria [21]. However, reported in another article, there is increase in the compressive strength by 15.28% of mortar treated with bacterial encapsulation [16] and an increment of 25%, 28 days compressive strength by bacterial remediation [33]. Incorporation of calcium nitrate encapsulated bacteria shows decrement in compressive strength of concrete by 10% comparative to control mix [19] and a 45% increase in the compressive strength of mortar by bacterial remediation [25]. There is an increment of 36% compressive strength of concrete containing bacteria Bacillus sp CT-5 [34] and 33% increase in 28 days compressive strength by utilizing a moderately alkalophilic aerobic bacteria Sporosarcina Pasteurii [35].

However, Incorporation of Sporosarcina Pasteurii shows 28 days and 91 days compressive strength 38.2 MPa and 44 MPa respectively [36] while incorporation of Bacillus Pasteurii show no negative effect on hardened properties of concrete [37, 38] while incorporation of Bacillus Pasteurii show no negative effect on hardened properties of concrete [37, 38]. Many authors reported increment of compressive strength depending upon the type of bacteria incorporated as 36% increment in compressive strength by using Bacillus Sp [2], 32.2% increment in compressive strength by using Bacillus Sphaericus [23] and incorporated as 36% increment in compressive strength by using Bacillus Pasteurii [23].

There is positive potential of using Shewanella in bio-concrete and observed increment of 17% and 25% in 7 and 28 days compressive strength respectively but no effective change due to Escherichia Coli in bio concrete [39] and also reported increment of 10% and 12% in compressive strength by incorporating Bacillus Pseudofirmus and Bacillus Cohnitto respectively [40]. So, Conclusion can be made that selection of microorganism is important to regain the properties of concrete [39]. Elastic modulus of concrete matrix containing micro-capsule shows increment of 21% comparative to conventional concrete [22]. As for tensile strength, there is an increment of 38.14% and 14.41% for 7 days and 28 days respectively by incorporating Baccilus Subtilisfor and 31.14% and 2.76% increase for 7 days and 28 days respectively by using Baccilus Sphaericus [32] and improvement of 30.94% by using bacterial called Bacillus Subtilis in split tensile strength comparative to conventional concrete [21]. Another author observes increase of 56% in tensile strength of microbial mortar when remediated with Enterobacter Sp. M2 microorganism [25].Similarly, the incorporation of Bacillus Sphaericus improves the tensile strength by 13.8%, 14.3% and 18.44% at 3, 7 and 28 days respectively [25]. Flexural strength reports conclude increment of 17.34% and 11.18% for 7 days and 28 days respectively by incorporating Bacillus Pasteurii [32] and reduction in 28 days flexural strength by 17% strength by using calcium nitrate encapsulation [19].

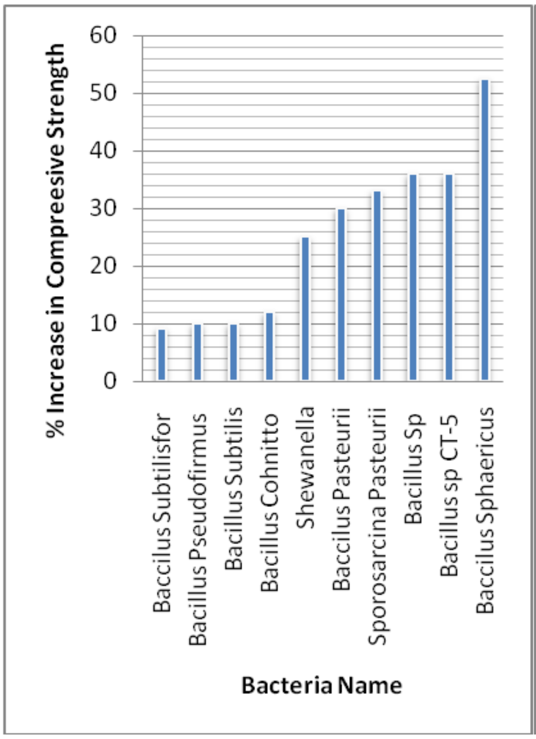

Fig 1: Influence on compressive strength by embedding different bacteria

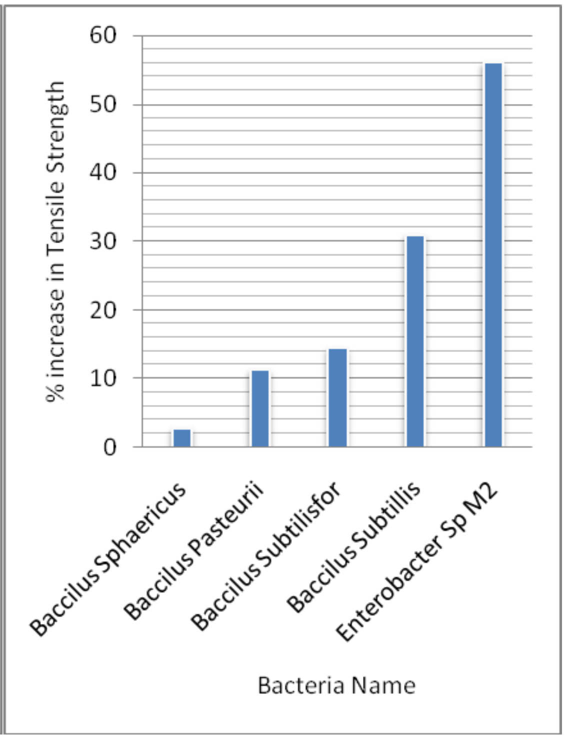

Fig 2: Influence on tensile strength by embedding different bacteria

DURABILITY PROPERTIES OF CONCRETE

As for durability concern, water permeability and chloride penetration reduces [16] by bio-remediating the concrete by incorporating Bacillus Cereus and Bacillus Pasteurii [17] compared to control mix. There is reduction in water absorption and porosity by incorporating Bacillus Halodurans Strain KG1 in the concrete mix by 205 and 12.4% at 91 days respectively [41] and also increase in resistance against penetration of water and hazard material and as max as 40% decrease in water absorption after 28 days bio remediation [25].By incorporation of Baccilus Sphaericus, concrete matrix performed better against permeability due to bio deposition [42]. Bio remediated concrete shows better resistance against chloride penetration compared to control specimen which is effective in reducing the rate of corrosion of reinforcement [43, 44]. Due to densification of interfacial transition zone in sporosarcina pasteurii treated concrete matrix show better resistance against water permeability compared to controlled specimen [34]. Another article reported the effect of Bacillus pasteurii on water absorption, porosity and chloride permeability on concrete matrix and found that there is decrease in permeability and porosity of the concrete [45] and addition of bacteria in mix reduces the capillary absorption capacity of concrete by an average of 20% compared to control mix [22]. Crack width is reduced by 48% and 63% at 14 and 28 days respectively compared to control mix [22]. SEM reports suggest direct involvement of the bacteria in production of calcite and calcium carbonate precipitation, further; it is confirmed through XRD and Energy Dispersive X-Ray analysis (EDX) [18]. Microstructure analysis has been done to confirm the presence of calcite in the form of calcium carbonate at the age of 28 days through XRD [17]. SEM micrograph confirms the alteration in strength due to agglomeration of un-hydrated particle on the surface of microcapsule and can be enhanced by the reduction of sulfonic acid needed for encapsulation [19].

CONCLUSIONS

From the experiments reported herein, the following conclusions may be made:

1. Self-healing of concrete yielded by using natural method and is environmentally friendly. It was done for improving the lifespan of concrete structure which indirectly improvise the sustainability of environment.
2. Effectiveness of crack repairing and regaining of lost strength is also depend on microorganism embedded in concrete matrix.
3. Mechanical properties also improve by incorporating bacteria as long term compressive and tensile strength increases depending on bacteria embedded.
4. Durability properties of concrete improve by incorporating bacteria as concrete perform better against water permeability, chloride ingression and water absorption.
5. SEM and XRD analysis confirms the precipitation of calcium carbonate which densifies the concrete matrix and ultimately improve the strength of concrete.

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