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DURABLE ASPECT OF BACTERIAL CONCRETE

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Abstract

Be known that concrete has the major building material largely used in building construction, and it has a large limitation with respect to their durability aspects. Detoriation a big reason through cracks, initialized due to various mechanisms just like shrinkage, freeze and thaw action. In addition of the mechanical properties as compressive strength, permeability, Elastic Modulus, flexure and split tensile strength etc., has to lead to the failure of the respective structure. As for enhancing the performance of concrete Bio-Mineralization a new method in concrete is evolved, the calcite precipitating spore forming bacteria or microbiologically induced calcium carbonate ($CaCo_3$) precipitation (MICCP) has been use now a days. In 1835 the bacteria has originally name vibrio Subtilis, and has renamed in 1872 as Bacillus Subtilis. Bacillus Subtilis also has more names including Bacillus Uniflagellatus, Bacillus globigii and Bacillus natto. According to the past investigation it has been framed out that the Bacillus Subtilis with a Concentration of 10^5 cells/ml at 35^0C gives better result in strength parameters. It has also been noted down that conventional concrete and self-compacting concrete (SCC) has the property of healing the minor cracks of concrete in initial stage, but the bacterial self-compacted concrete up to 40mm depth with crack width 0.52mm has reduces crack width up to a level of 0.18mm at 21 days has been recorded.

Key words: Bacteria encapsulation, Calcite Precipitation, MICCP, SCC, Self-healing Concrete.

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1 Introduction

Concrete is one of the most used building materials. However, it is one of the major producers of carbon dioxide (CO_2) which is directly contributing to destroying our environment. Not to mention that enormous costs are being spent each year to maintain concrete constructions. Cracks of various sizes form in all concrete constructions which need to be sealed manually shortening the life of a particular construction. In view of the above the self-consolidating concrete (SCC) is the primary alternative which is a highly flowable type of concrete that spreads into the form without the need for mechanical vibration. Self-compacting concrete is a non-segregating concrete that is placed by means of its own weight. The importance of self-compacting concrete is that maintains all concrete's durability and characteristics, meeting expected performance requirements. But in the self-compacted concrete process the healing problem has not rectified completely. In that case self-healing concrete (SHC) or bio-concrete is a revolutionary building material that has the solution to all these problems and is definitely the building material of the near future.[1]

2 Self-healing approach

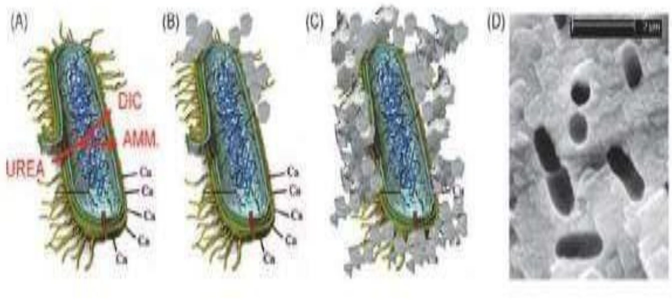
The principal phases of the natural healing ability are the inflammation and hydration of cement pastes; followed by the precipitation of calcium carbonate ($CaCO_3$), and lastly the obstruction of flow paths as a result of the deposition of water impurities or the movement of some concrete bits that get detached throughout the cracking process. Many factors are considered in the natural way of healing, such as; temperature, degree of damage, freeze-thaw cycles, the age of the concrete and the mortar state. As for the artificial way to repair cracks in concrete, which is man-made self-healing process was first invented in 1994. The main method and first approach was to use a healing agent (adhesive) which is encapsulated inside a micro capsule, once a crack forms, it causes the micro capsules to break, releasing the healing agent, hence healing the crack. The adhesives can be stored in short fiber or in longer tubes.[7, 38]

Self healing approach and ways of applying bacteria

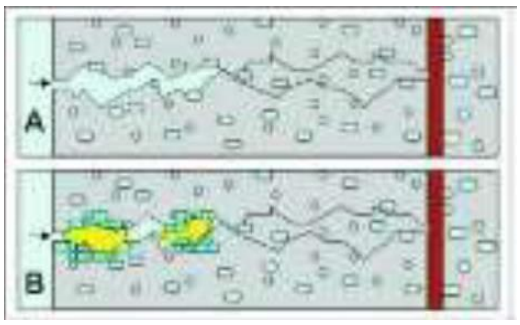
The bacteria to be used as self-healing agent in concrete should be fit for the job, i.e. they should be able to perform long-term effective crack sealing, preferably during the total constructions life time. There are many approaches to create smart concrete and enhance its properties while reducing the cost of overall use of the material. Many of these approaches were dedicated to create SHC; two of the main approaches have proved to be efficient and easy to use.

(a) **Bacteria-Based Healing Process.** Also known as Bio-Concrete; this kind of concrete uses a simple process to close the formed crack. The main mechanism is achieved by making a concrete mixture that contains (i) a precursor like calcium lactate ($Ca(C_3H_5O_2)_2$) and, (ii) bacteria planted in micro capsules (or just added to the mixture) that will later germinate, once the water reaches the crack. As soon as the bacteria germinate, they produce limestone ($CaCo_3$) caused by the multiplying bacteria Fig 1 (a). Dr. Richard Cooper of Bath's Department of Biology & Biochemistry says that incorporating bacteria in concrete adds a double layer shield in order to prevent corrosion in steel. Not to mention that it employs oxygen present which would then benefit the process of steel corrosion.[1] The bacteria which are applied in this kind of concrete are Spore-forming and alkali-resistant bacteria. Bacteria from this group are the most suitable as they are spore-forming and can live for more than 200 years in dry conditions[49] Therefore, using bacteria as a healing mechanism is one of the best mechanisms to produce this kind of concrete because of its sustainable organic properties.

(b) **Shape Memory Polymers based healing process**. New smart materials (SMP) that are capable of returning to their initiative state by changing back their form upon applying a stimulus.[31] This mechanism employs both the autogenic and autonomic principles. It uses a man-made system to increase the natural autogenic healing and seal cracks in concrete. This kind of polymers is semi-crystalline polymers that have a pre-defined shape memorized in their structure that later helps the polymers to go back to their original state. When a crack occurs, the system will be triggered hence, the shape memory polymer within the crack gets activated through heating which can be in the form of direct heat, or an electrical current. As soon as it's activated, the shape memory effect or shrinkage takes place, and due to the restrained nature of the tendon, a tensile force is generated, hence the crack closes on itself. After that, the autogenous healing starts taking place.



(a) Calcite precipitation by bacterial cell



(b) Bacterial self-healing process

Fig 1

Effect of the pH on the Growth of the Bacteria

A microbial process which leads to an increase of both pH & the concentration of dissolved inorganic carbons is the utilization of organic acids [4, 28]. Sub surface bacterial ureolytic activity could produce NH_4^+ and bicarbonate ions and thus increase the pH, which results in $CaCO_3$ production. Urease catalyzes the hydrolysis of urea to CO_2 & ammonia resulting in an increase of pH and carbonate concentration in the bacterial environment. MICCP occurs for a pH range of 8.3-9.0, for which urease activity remains high [50]. When ammonia has used to form calcium carbonate precipitate, the pH is

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controlled between 8 and 11 [39]. Photo calorimeter was observed that the growth in pH range 7.5-9.0 [30]. Basillus pasteurii had the growth in pH range of 7.0–9.0 and bacillus spharicus was 8-9 [59]. The pH of the highly alkaline Concrete lowers to the values in the range of 10 to 11.5 where the bacteria spores become activated. There are many bacteria other than bacillus which are survived in the alkaline environment.

Mechanism of applying the healing agents in concrete. The principle mechanism of bacterial crack healing is that the bacteria themselves act largely as a catalyst, and transform a precursor compound to a suitable filler material. The newly produced compounds such as calcium carbonate-based mineral precipitates should than act as a type of bio-cement what effectively seals newly formed cracks Fig1 (b). Thus for effective self-healing, both bacteria and a bio-cement precursor compound should be integrated in the material matrix. However, the presence of the matrix-embedded bacteria and precursor compounds should not negatively affect other wanted concrete characteristics. Bacteria that can resist concrete matrix incorporation exist in nature, and these appear related to a specialized group of alkali-resistant spore-forming bacteria [23]. Interesting feature of these bacteria is that they are able to form spores, which are specialized spherical thick-walled cells somewhat homologous to plant seeds. These spores are viable but dormant cells and can withstand mechanical and chemical stresses and remain in dry state viable for periods over 50 years.

3 Effect of bacteria on properties of concrete

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.

Hydration kinetics

(a) Bio-Concrete-Mechanism. The Process of Calcite precipitation has influenced by the decomposition of urea by bacteria, with aid of bacterial urease enzyme. As a result of metabolism of bacteria species give urease that catalyses' urea to ammonia and carbonate. Further these components hydrolyze to carbonic acid and ammonium chloride that lead to the formation of calcium carbonate (calcite crystal)[25].

$$CO(NH_2)_2+H_2O \rightarrow NH_2COOH+NH_3 \quad (a)$$
$$NH_2COOH+H_2O \rightarrow NH_3+H_2CO_3 \quad (b)$$
$$H_2CO_3 \rightarrow HCO_3^- +H^+ \quad (c)$$
$$2NH_3+2H_2O \rightarrow 2NH_4^+ +2OH^- \quad (d)$$
$$HCO_3^- +H^+ +2NH_4^+ +2OH^- \rightarrow CO_3^{2-} +2NH_4^+ +2H_2O \quad (e)$$

In calcite precipitation a key role has played by surface of bacteria, it is negatively charged and of neutral ph. The calcium ions with positive charge can combine with surface of bacteria there by encouraging nucleation [17,29,35,45,47,52]

$$Ca^{2+} + Cell \rightarrow Cell - Ca^{2+} \quad (f)$$
$$Cell - Ca^{2+} + CO_3^{2-} \rightarrow Cell - CaCO_3 \downarrow \quad (g)$$

(b) Microbially Induced Calcium Carbonate Precipitation (MICCP)

According to the Sumit joshi et al.[20] MICCP has the capability of microbes to form calcium carbonate extracellurly through a metabolic activity. The property of mineral formation by different bacteria species like sulphate reducing bacteria (SRB), silicate associated bacteria, unicellular cyanobacteria & urea degrading bacteria has been counted [18]. Sufficient amount of calcium & carbonate ions has required for the $CaCO_3$ precipitation so that the ions activity

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product (IAP) exceeds the solubility constant (Kso) as in equations (a) & (b), from the comparison of the IAP with the Kso the saturation state (Ω) of the system can be defined; if Ω > 1 the system has oversaturated & precipitation has likely as [41],

$$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3 \quad (a)$$

$$\Omega = \alpha\,(Ca^{2+})\alpha\,(CO_3^{2-})/Kso \quad \text{with } Kso \text{ calcite, } 25^{\circ} = 4.8 \times 10^{-9} \quad (b)$$

The concentration of carbonate ions has related to the concentration of dissolved inorganic carbon (DIC) and the pH of a given aquatic system. Also the concentration of (DIC) depends on temperature and the partial presence of carbon dioxide (Exposed to atmosphere). The equilibrium reactions and the constants governing the dissolution of CO_2 in aqueous media (25^{o}C and 1atmp) have given in eqns: (c), (d), (e) and (f) [60].

$$CO_2\,(g) \leftrightarrow CO_2\,(aq) \quad (P\,K_H = 1.468) \quad (c)$$

$$CO_2\,(aq) + H_2O \leftrightarrow H_2CO^*_3 \quad (PK = 2.84) \quad (d)$$

$$H_2CO^*_3 \leftrightarrow H^+ + HCO_3^- \quad (PK1 = 6.352) \quad (e)$$

$$HCO_3^- \leftrightarrow CO_3^{2-} + H^+ \quad (PK2 = 10.329) \quad (f)$$

With $H_2CO^*_3 = CO_2\,(aq) + H_2CO_3$ broadly two different metabolic pathways in the process of bio mineralization associated with the microorganisms: (a) Auto trophic pathways (b) Heterotrophic pathway.

(i) Autotrophic-mediated pathways

In the autotrophic–mediated pathways, calcium carbonate precipitation is induced by microbes with the conversion of carbon dioxide in the presence of calcium ions in its immediate environment. Autotrophic precipitation of carbonates includes non-methylotrophic, methanogenesis, anoxygenic photosynthesis and oxygenic photosynthesis [8,9,14,47]. All of these autotrophic pathways use carbon dioxide as a carbon source.

(ii) Heterotrophic-mediated pathway

In heterotrophic-mediated pathways, carbonate precipitation occurs either by sulphur cycle or nitrogen cycle. Sulphur cycle has carried out by sulphur reducing bacteria (SRB) via dissimilatory reduction of sulphate [9]. As the organic matter is degraded by SRB, bicarbonate ions and hydrogen sulphide are produced by bacterial action using SO_4^{2-} as a terminal electron acceptor as shown in Eqn.g [16,25,39]. According to peckman et al [41] reported that gypsum present in cavities provides the calcium ions for aragonite precipitation and sulphate ions for the metabolic process of sulphate reducing bacteria as shown in Eq (h) degradation of organic matter in anaerobic condition provides the increased alkaline condition & facilitates the formation of aragonite crystals.

$$2CH_2O + SO_4^{2-} \longrightarrow H_2S + 2HCO^{-3} \quad (g)$$

$$CaSO_4.\,2H_2O \longrightarrow Ca^{2+} + SO_4^{2-} + 2H_2O \quad (h)$$

(c) MICCP via urea hydrolysis. Sumit joshi et al [20] In the Process one mole of urea has hydrolyzed intracellularly to 1ml of ammonia and 1ml of carbonate which spontaneously hydrolyses to form 1ml of ammonia and carbonic acid as Eqs (i) & (j)

$$CO\,(NH_2)_2 + H_2ONH_2 \xrightarrow{\text{Bacteria}} COOH + NH_3 \quad (i)$$

$$NH_2COOH + H_2O \longrightarrow NH_3 + H_2CO_3 \quad (j)$$

These products further equilibrate in water to form bicarbonate and 2 mol of ammonium and hydroxide ions (Eqs. K & l).

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$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \quad (k)$$

$$2OH^- + H_2CO_3 \leftrightarrow CO_3^{2-} + 2H_2O \quad (l)$$

Generation of ammonia on the hydrolysis of urea [50]. Presence results in pH increase creating an alkaline condition in the micro environment around the bacterial cell of calcium ions in the surroundings of bacterial cell wall results in the precipitation of calcium carbonate as the super-saturation is reached as shown in Eq (m)

$$CO_3^{2-} + Ca^{2+} \leftrightarrow CaCO_3 \quad (m)$$

Bacterial cell surface plays an important role in precipitation of calcium carbonates nucleation site as shown in Eqs. n, o & p

$$Ca^{2+} + Cell \longrightarrow Cell\ Ca^{2+} \quad (n)$$

$$Cl^- + HCO_3^- + NH_3 \longrightarrow NH_4Cl + CO_3^{2-} \quad (o)$$

$$Cell{-}Ca^{2+} + CO^{2-} \longrightarrow Cell\ CaCO \quad (p)$$

Compressive strength

The standard compressive Machine has been used to determine the relative strength of concrete samples of different grades. Three different concentrations of Bacillus Subtilis 10^3,10^5 & 10^7cells/ml has been used and found out that 10^5 cells/ml was more efficient for crack healing, also achieved highest compressive strength [31]. The bacterial Fly ash concrete does not affect the workability aspect; the addition of bacteria increases the compressive strength up to 7.5% for M_{20} and 8% for M_{40} grade of concrete at 28 days. [43,35] It was observed that with the addition of bacteria bacillus Subtilis the compressive strength of M_{20}, M_{40}, M_{60} & M_{80} at ages i.e. 28, 60 and 90 days showed significance increase by nearly 25% in all grades of concrete proposed for all ages [42]. The improvement in compressive strength by bacillus Subtilis strain 121 is probably due to deposition of calcite ($CaCo_3$) in cement sand matrix of microbial concrete which remediate the pore structure with in the mortar. The compressive strength of M_{20} was recorded as 29.13MPa at 28 days. [34] 49.77MPa for M_{30} with B. Subtilis 56x10^6 cells/ml at 28 days [21], 11.96% increase in Bacterial concrete M_{20} with 10^5cell/ml [26]. Bacterial self-compacting concrete M_{40} with 20% replacement of cement with Micro silica gives the compressive strength 47.17 MPa. [3]

Water permeability

The saline buffer has been used to determine the increased resistance of concrete block towards the water penetration, the water absorption of normal concrete block has 9.79% and concrete block treated with potent ureolytic bacterial BH-3 strain has 4.91%, which shows the decrease in water absorption capacity.[18] The depth of penetration of water in bacterial concrete has also decreased when compared to conventional concrete which is of about 33%, due to the filling of microspores by calcite.[26] The mortar specimen with hydrogel-encapsulated spores healed crack width of about 0.5mm and the water permeability was decreased by 68% compared to control concrete.[20] Against the specification suggested by MORT & H 4th revision clause 1716.5. Results shows that the presence of bacteria resulted in lower coefficient of permeability of range 0.23-0.27x10^{-9}m/sec in comparison to controlled concrete which has coefficient of permeability of 0.95-2.31 x10^{-9} m/sec for various grade of concrete. Water permeability reduces in bacterial concrete by nearly 70-90% from low to high grades suggesting that reduction in the permeability is due to reduction in the porosity of the concrete resulting from pore filling by calcite crystal.[42] After performing the experiment it was found that the value of K range from 4x10^{-6} m/sec to 7x10^{-6} m/sec.[30]

Gas permeability

RILEM-CEMBUREAU method was used to find the gas permeability using the principal as

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the Hagen-poiseuille relationship for laminar flow of a compressible fluid through a porous body having small capillaries under steady state. Martin sommer oxygen permeability experiment used measure the rate of flow of oxygen. It was seen that there is a reduction of permeability in bacterial concrete as compared to the conventional concrete.[30] All treatment gave rise to a decrease in permeability towards oxygen. The highest reduction in permeability was obtained with treatment (1-4) surface coating and (17) penetrating polyurethane sealant. Reduction of permeability due to bacterial treatment occurred to the same extent as for treatment with penetrating sealants. [59]

Rapid chloride permeability

Corrosion is mainly caused by the ingress of chloride ions into concrete annulling the original passivity present. Rapid chloride permeability test (RCPT) has been developed as a

Fig. 2 Rapid Chloride Permeability Apparatus

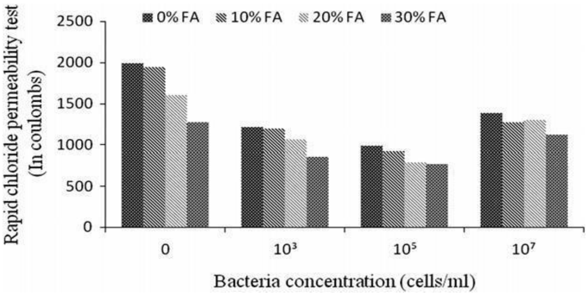

Fig 3 Variation of permeability with Bacteria concentration

quick test able to measure the rate of transport of chloride ions in concrete (Fig 2). This test was conducted as per ASTM method. Results of the effect of bacteria on the rapid chloride permeability of fly ash concrete at the age of 28 days shown in Fig 3. It is clear that with the inclusion of bacteria, chloride ingress capacity of fly ash concretes decreased with the increase in bacteria concentration. Maximum reduction in chloride ions was observed with 10^5cells/ml for all fly ash concretes however, concrete with 30% fly ash gave 762 coulombs penetration which is considered to be very low. The ability of concrete to resist the penetration of chloride ions is a critical parameter in determining the service life of concrete structures exposed to deicing salts or marine environments. The concrete containing fly ash along with optimized dose of bacteria (S. pasteurii) showed good resistance towards rapid chloride penetration [6]

Microstructure

Microbial calcite formation is directly dependent on the availability of urea as a substrate for urease activity and Ca^{+2} derived from an appropriate source [46]. As long as the whole or the major part of these salts is utilized by microbial activity, their increasing concentration would result in a greater calcification and a corresponding increase in the mortar strength. However, the unutilized amount of salts would obviously have a negative impact.

SEM Micrographs The micrographs of the control plain cement mortar and of a better-performing bacteria-modified mortar are presented in Fig 4 (a), (b) respectively. Figure (b) SEM images of cement mortar specimen showing filler strands of calcite formed by bacterial mineral precipitation which are magnified in the upper two images at magnifications of 5452× and 6000× Fig 4 (a), (b) indicate that in a mortar made with a 10^8 cells/ml of *S. pasteurii*, the pores are better filled with narrow strands of filler Fig (b); and a higher modification in pore size distribution is noticed, whereas no such filler material is observed in the micrographs of the control sample of plain mortar Fig (a). This confirms the increase in compressive and direct tensile strengths. The qualitative assessment of SEM images shows that the presence of narrow strands of filler is beneficial for modification of the porosity and pore-size distribution of cement mortar. In congruence with our findings, several studies

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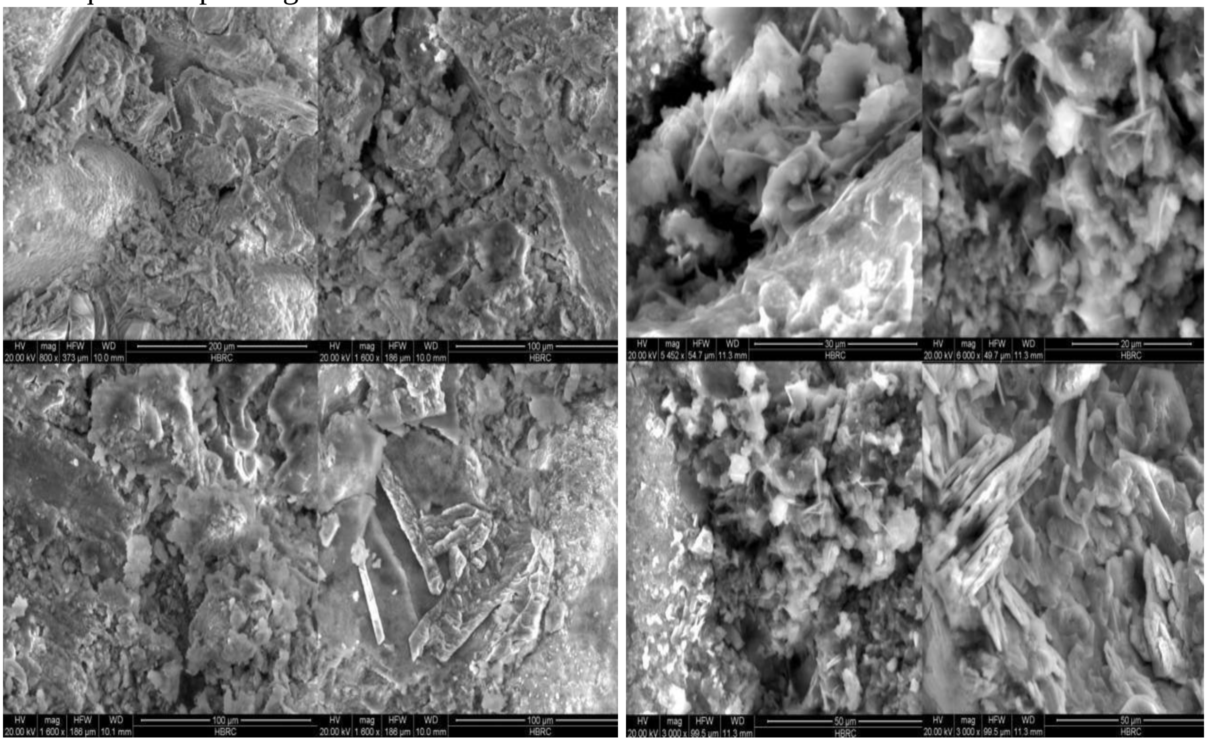
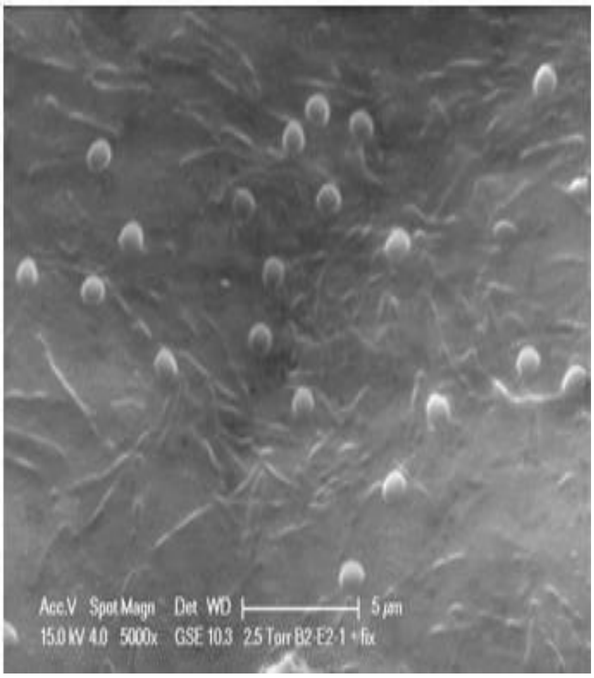
addressing the microbial calcification have shown deposition of calcite crystal in cement mortars in SEM images, which demonstrate the real possibility of application of this technique in improving the cement mortars[46,23].



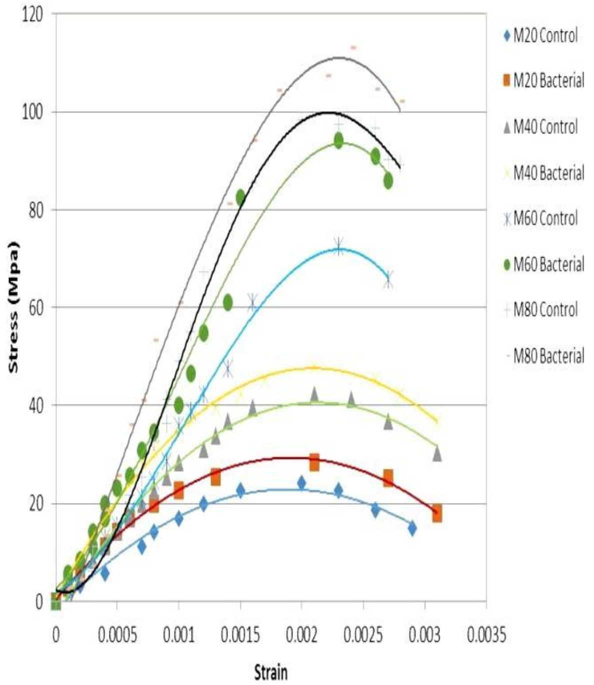
(a) SEM images of cement mortar specimen (control) (b) SEM images of bacteria-modified mortar

Fig 4



Photomicrograph (5000x magnification) of Alkali-Resistant spore forming bacterium (B. strain B2-E2-1) [23]

Fig 5



Stress strain variation of control concrete and Bacterial concrete with different grades of Mix

Fig 6

4.0 Stress-Strain Behaviour of Concrete

The stress strain behaviour of concrete gives the value of toughness. The test was performed on the cylindrical specimen prepared in UTM of 3000 KN capacity & found the stress 72.61 MPa against the strain value of 0.23 of controlled concrete where as it was of 94.21 MPa in bacterial concrete at same strain value of 0.23, which shows the increase in the stress value in bacterial concrete [30] The relationship between stress and strain is important in understanding the basic elastic behaviour of concrete in hardened state. The observation made from stress strain curves in all grades of bacterial concrete have shown improved stress values for the same strain levels compared to that of conventional concrete mixes Fig 6. The increase in E value has shown nearly 20-30% for low to high grade of bacterial concrete [42]

5.0 Application of Bacteria In Construction Area

The use of microbial concrete in Bio Geo Civil Engineering has become increasingly popular. From enhancement in durability of cementitious materials to improvement in sand properties, from repair of limestone monuments, sealing of concrete cracks to highly durable bricks, microbial concrete has been successful in one and all. Application of various bacteria in construction area by various authors shown in Table 1 and other application of bacteria in construction area shown in Fig 7. [55] This new technology can provide ways for low cost and durable roads, high strength buildings with more bearing capacity, long lasting river banks, erosion prevention of loose sands and low cost durable housing. The next section will illustrate detailed analysis of role of microbial concrete in affecting the durability of building structures. Another issue related with conventional building materials is the high production of greenhouse gases and high energy consumed during production of these materials. The emission of greenhouse gases during manufacturing processes of building materials is contributing a detrimental amount to global warming. Along with this, high construction cost of building materials is another issue that needs to be dealt with. The above mentioned drawbacks of conventional treatments have invited the usage of novel, ecofriendly, self-healing and energy efficient technology where microbes are used for remediation of building materials and enhancement in the durability characteristics. This technology may bring new approaches in the construction industry. Thus, bacterial material as a smart material than it can be utilize in various construction area to improve the performance if structure in new era.

Table 1 Application of various bacteria in construction area

Application	Organism	Reference
Cement Mortar Concrete 	Bacillus Cereus Bacillus sp CT 5 Bacillus Pasteurii Shewanella Sporosarcina pasteurii	Le Metayer Leveral et al. 1999 Achal et al. (2011 b) Ramachandran et al (2001) Ghosh et al. (2005) Achal et al. (2011 a)
Remediation of cracks in concrete 	Sporosarcina pasteurii Bacillus pasteurii Bacillus pasteurii Bacillus spharicus Bacillus spharicus	Bang et al. (2001) Ramachandran et al. (2001) Ramakrishnan (2007) De Belie et al. (2008) De Muynk et al. (2008 a,b)
Self-healing 	Bacillus pseudifirmus Bacillus cohnii	Jonkers et al. (2007)

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Fig 7. Application of various bacteria in construction area

Discussion

The Bacillus Subtilis can be produced from laboratory which is cost effective and safe, it improve the hydrated structure of cement mortar. Microbiologically induced $CaCo_3$ precipitation results from a series of complex biochemical reactions of bacteria which results in self-healing of concrete [8,31].The Compressive, Split Tensile and Flexural strength of M_{20}, M_{25}, M_{30}, M_{40} grade of Concrete increases, the bacteria incorporated RCC slab specimen withstands more load before starts yielding than that of control concrete slab specimen [7]. The "Smart Bio Materials" (Microbial Concrete) shows significant reduction in water absorption capability by using Bacillus Subtilis & efficient healing was shown in reduction in crack size from 0.43mm to 0.18mm in width at 21 days of inoculation [15,32]. When the bacteria added with fly ash do not affect its workability aspects of concrete [42]. In the visual evaluation of biological healing of Shotcrete cracks confirmed the satisfactory performance of calcium carbonate precipitating bacteria in the healing of the cracks in Shotcrete. Scanning electron micrographs (SEM) analysis confirmed the presence of calcite induced by bacteria [20]. Bacillus Subtilis with recycled aggregate increases the performance in the presence of H_2SO_4 [24]. Calcium carbonate precipitation by B. Subtilis in the form of calcite has been confirmed through microstructure analysis using SEM, EDX and XRD. Bacillus Subtilis decreases the drying shrinkage strain and capillary water absorption of RCA concrete and there by enhances the durability. Air content in bacterial RCA concrete can be reduces perhaps by increasing the mixing time to allow the extra air to go out of the concrete mix [28].The spore forming bacteria can remain in concrete for 200 years and it can be an effective method as $CaCo_3$ precipitation is a by-product of urease hydrolysis, so the reactant will remain even after the completion of one reaction. The other chemical that are used for crack healing will remain for one application only [41]. Hydrogel was used as the bacterial carrier in concrete for self-healing cracks and acts as water reservoirs for continuous crack healing (Autogenic, Biogenic). Carbonate precipitating bacteria can precipitate $CaCO_3$ in/on hydro gel. Crack of a width 0.5 mm can be completely healed in the specimens with bio-hydro gels embedded. Bacterial based self-healing is a potential solution for sustainable development of concrete[22]. Optimal bacterial self-compacting concrete (SCC) containing RHA SCC with 15% RHA shows the best performance. A bacterial concentration of 10^5 cells/ml leads to the best mechanical properties. Concrete mixes fabricated with a bacterial concentration of 10^7 cells/ml exhibit the best durability. Over 70% reduction in permeability-related properties is obtained at the maximum bacterial concentration [13].

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