# Economical and Sustainable Structure Design Using Bio Concrete

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***Abstract*— As we all know concrete is the most widely consumed construction material on the earth, with its consumption rate increasing continuously over the period. One of its kind developed material is bio concrete or self-healing concrete. Bio concrete constitutes of conventional concrete mix with bacterial agents (bacillus along calcium lactate), ability to heal cracks and resistance towards corrosion is the main mechanism to be carried out. After several research and analysis, it is proven that the bio concrete is more efficient, durable, safe, convenient over conventional concrete mix on the bases of physical, chemical and mechanical properties. Most desirable to implement the bio concrete in construction under-water or in hydraulic environment. (tunnels, bridges, water retaining infrastructures etc.) In this paper our primary objective is to focus on the economical approach to bio concrete mix, with minimum maintenance cost over the service life of structures and sustainable design for greater adaptability in construction works. The greater demand of concrete is leading to exhaustion of minerals and cores due to which the extensive use of concrete should be optimized, the environmental degradation and lower accessibility to water is also the major concern.**

**By this paper our aim is to motivate the young scientists to undergo evolution for its application in construction industry and also to attract the attention of researchers over the issue. Need of infrastructure and development in country like India, Bangladesh, Nepal etc. (developing nations) is prominent, so the use of bio concrete is an innovation in advance concrete technology for sustainable future**

***Index Terms*— Sustainable design, Economical approach, Environmental Degradation, Bio concrete mix**

## I. INTRODUCTION

Concrete being the mainly utilized construction material, contains ingredients of cement, fine aggregate, coarse aggregate and water. It is computed that above 30 million tons of concrete is being produced and consumed every year [1]. As we know the reinforced concrete made structures are generally prone to shrinkage, cracking and steel corrosion due to external loading over the long period of time. Concrete is weak and vulnerable to break in tension, while strong in compressive forces. Cracking of the concrete was classified as the most detrimental effect in the building industry, whereas bridges, underground and water-retaining infrastructures were identified as the most vulnerable objects [2]. Fig. 1 classifies damages, which were identified in the building structures.

During the last decade, the scientific community has turned to the self-healing technologies as a promising and sustainable solution to increase the durability thereby prolonging the service life of structural concrete, and reducing expenses of the maintenance and repair. The idea of self-healing concrete employs the recovery of material properties without any human intervention. In other words, material defects are healed autonomously. Several self-healing techniques were developed for concrete structures.[3] The implementation of bio concrete enhances the service life of concrete structures, reduces repair and maintenance costs and thus leads to decrease of new construction works which also reduces the utilization of raw materials, savage in energy consumption. This finally results to decelerate carbon dioxide emissions due to cement plant into atmosphere as the hydration is completely done in intail peroid of bio concrete settling [4] Microbial self-healing technology uses microbial metabolism to produce relatively insoluble compounds, such as calcium carbonate, to achieve self-healing of concrete, which show a good future development and commercial application among those self-healing technologies. [5]

This paper assesses the sustainable design of structures i.e. associated with impacts of global warming and pollution, along with different bacterial combination to opt out cost effective concrete mix which will eventually bring the low maintenance cost over the service years of structures

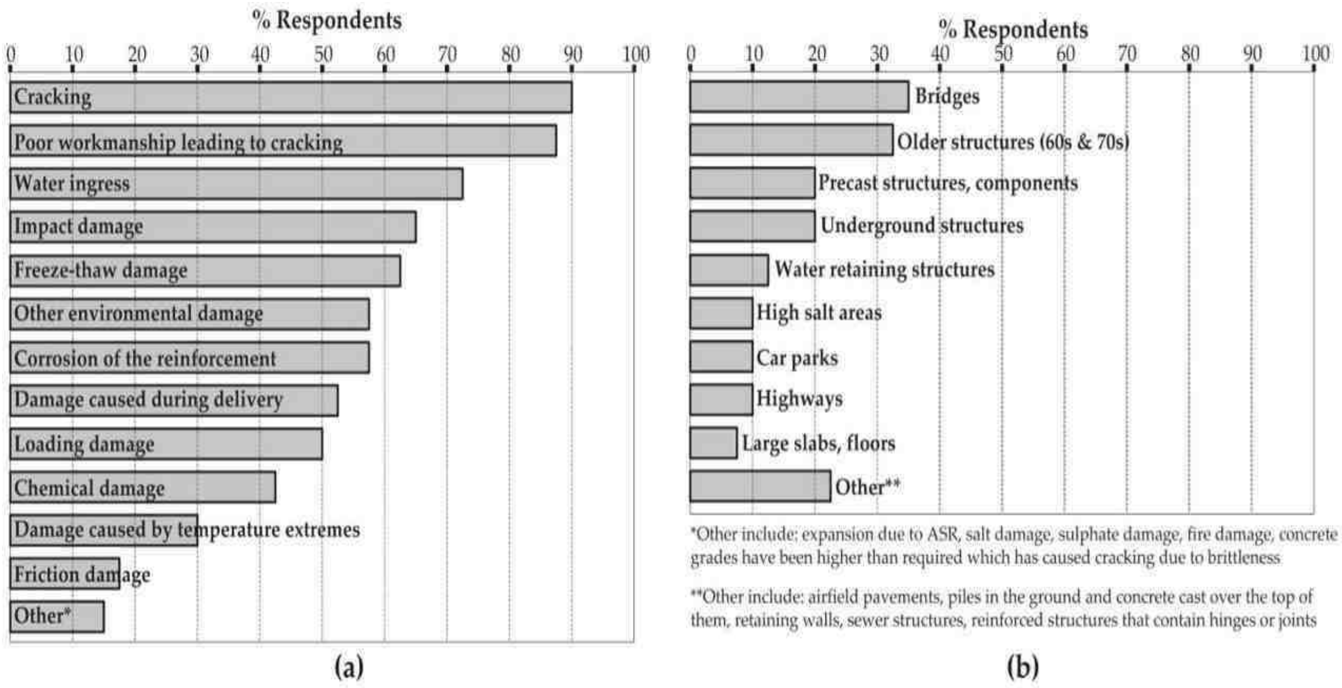


Fig. 1. The main causes of damage in concrete structures (a) and structures that are most vulnerable to damage (b). Adopted from [2]

## II. BIO CONCRETE OR SELF-HEALING CONCRETE MIX

This type of mix is generally prepared by adding of bacterial agents in conventional prepared concrete mix, the bacterial categories used are such as Bacillus subtilis, bacillus pasteuri species in healing mechanism. Cracks less than 0.2 mm in concrete can be filled by concrete itself. But if cracks are more than 0.2 mm then concrete fail to heal itself which create a passage to deleterious materials. [6.12] Therefore, the need of bio concrete occurred which can be the best substance to be applied over the surface.

In self-healing concrete, formation of any cracks, leads to activation of bacteria from its stage of hibernation. By the metabolic activities of bacteria, during the process of selfhealing, calcium carbonate precipitates into the cracks healing them. Once the cracks are completely filled with calcium carbonate, bacteria return to the stage of hibernation. In future, if any cracks form the bacteria gets activated and fills the cracks. Bacteria act as a long-lasting healing agent and this mechanism is called as Microbiologically Induced Calcium Carbonate Precipitation (MICP). [6,12]

Calcium carbonate will be formed on the control concrete surface as a result of the $CO_2$ reaction with calcium hydroxide present in the concrete matrix as follows:

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

In this situation, the production of calcium carbonate is due to a limited amount of $CO_2$. Since $Ca(OH)_2$ is a soluble mineral, it is dissolved in water and diffused in the form of leaching out of the crack [7,8]

In self-healing concrete, 6.82 kg/m3 of healing agents was used, and the masses of the bacteria spore powder and calcium source were 1.13 kg/m3 and 5.69 kg/m3 respectively. For the healing agent was added to replace fly ash of the same quality, the mixture proportion of microbial self-healing concrete should be adjusted (Table 2). [9]
In order to verify the adaptability of microbial self-healing concrete to the design mix proportion, the above mix proportion were used to test the normal concrete and microbial self-healing concrete. The results showed that no segregation and bleeding were observed, and the addition of the self-healing agent did not affect the workability of the concrete. The self-healing agent had good adaptability to the existing concrete mix proportion.[9]

Unit:kg/$m^3$

| water | Cement | Sand | Gravel | Fly ash | Water reducer |
|---|---|---|---|---|---|
| 150 | 307 | 725 | 1134 | 34 | 2.728 |

Table 1 normal concrete mix proportion

Unit:kg/$m^3$

| water | Cement | sand | Gravel | Fly ash | Water reducer | Spore powder | Calcium source |
|---|---|---|---|---|---|---|---|
| 150 | 307 | 725 | 1134 | 27.18 | 2.728 | 1.13 | 5.69 |

Table 2 microbial self-healing concrete mix proportion

Fig2: table 1 shows normal concrete mix proportion, table 2 shows microbial self-healing concrete mix proportion adopted from [9]

2.1 MECHANICAL PROPERTIES

2.1.1 COMPRESSIVE STRENGTH

After formation of concrete, the foremost test under which it goes is of compression forces laid upon its area. The strength of the concrete is most important from aspect of civil engineering as the whole foundation to super built-up structure stability is primarily dependent on the mix, type of cement, water-cement ratio, quality of aggregates etc included in preparation of concrete.

After several researches is proven that the compressive strength recorded after 7th ,14th and 28th days of the curing of concrete cube block, the block made of self-healing concrete shows greater compressive strength and composure compared to conventional concrete. It's one of the vital property bio concrete for its mass implication in the field of construction and engineering.

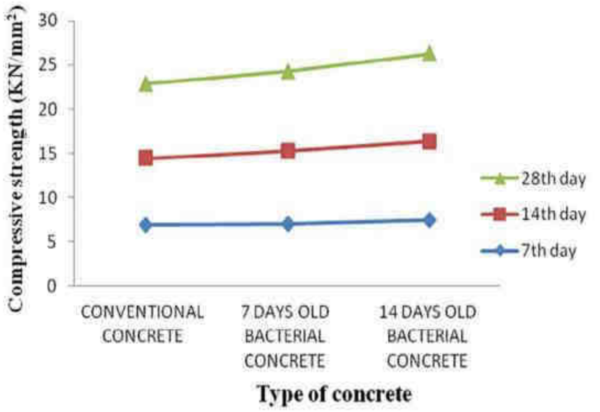


Fig3: comparison of compressive strength of concrete adapted [10]

2.1.2 FLEXURAL STRENGTH OF CONCRETE

As we know the measure of flexural strength in concrete is usually shown in tensile strength of concrete expressed in modulus of rupture which is mostly 10-20% more than that of compressive forces.

Similarly, alike in determining compressive strength of concrete the same was carried out by researchers for knowing tensile strength of concrete. In which the bio concrete possessed more flexural strength compared with conventional concrete when tested on 7th, 14th and 28th day of curing concrete blocks

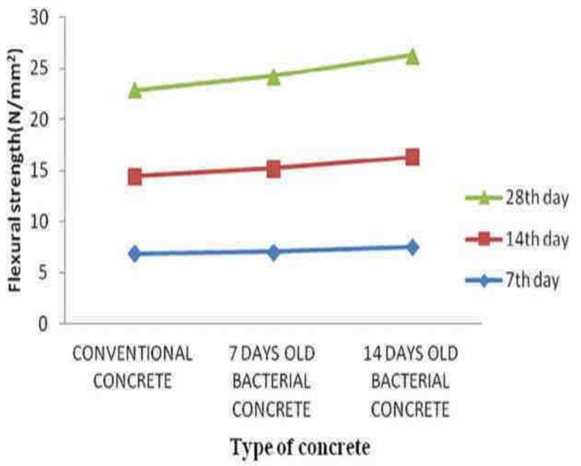


Fig4: comparison of flexural strength of concrete adapted [10]

2.2 DURABILITY PROPERTIES

2.2.1 WATER ABSORPTION

The water absorption test was done for 7 and 28 days of curing for both normal concrete and bacterial concrete mixes. The calcite excreted by bacteria filled the micro cracks increasing the nonporous nature of the concrete results in decrease in water absorption of bio concrete samples. The water absorption decreases from 1.26% of conventional samples to 0.23% for bacterial mix samples after cracking cured for 28 days. The results of water absorption test are shown in table 3. [11]

| S.No | Mix | Age of curing | Dry weight (W1) | Wet weight (W2) | % loss weight |
|---|---|---|---|---|---|
| 1 | | 7 | 8.61 | 8.75 | 1.626% |
| 2 | NC | 28 | 8.70 | 8.81 | 1.264% |
| 3 | | 7 | 8.61 | 8.66 | 0.58% |
| 4 | BC | 28 | 8.70 | 8.72 | 0.23% |

Table 3 water absorption values for normal and bacterial concrete samples,[11]

2.2.2 SORPTIVITY TEST ON CONCRETE

One of the most useful tests laid on concrete in hydraulic conditions, the concrete immersed in water bodies are at higher risk of corrosion and weakening, therefore it is mandatory to determine the permeability of liquids in concrete.

The Sorpitivity test has done for both ordinary and bio concrete mix samples for 7 and 28 days of curing. Bio concrete specimens offers good resistance intended for water penetration, after cracking cured for 28 days as the absorbance goes on declining compared to normal concrete samples. The precipitates produced by the bacteria in the pores of concrete improve the denseness of bio concrete specimens leads to decrease in Sorpitivity values. The results of Sorpitivity are shown in Fig. 5.[11]

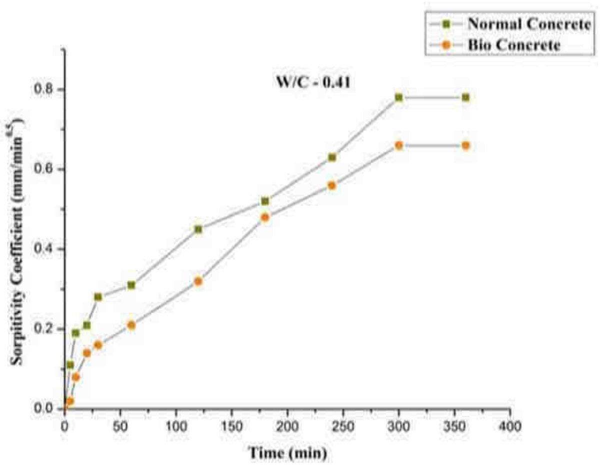


Fig5: comparison of sorpitivity coefficient for normal and bacterial concrete samples [11]

## III. ECONOMICAL APPROACH

Cost effective materials always have slight edge over their substitutes in construction industry, it is known that the conventional concrete is cheaper than the bio concrete but however we can suggest some measures from the overall life of structures depending on the factors:

- From water absorption test it is known that the bio concrete absorbs less water than conventional concrete due to non-porous nature generated by calcite bacterial compounds. Therefore, bio concrete reduces the demand and consumption of water for preparing the mix.
- Mainly used microbial self-healing agents Bacillus subtilis, Bacillus mucilaginous, Bacillus pasteurii, Bacillus sphaericus etc are posting favourable results in commercial usage of bio concrete but researchers and scientists are continuously working to adapt more feasible organic compound for making substitute of existing materials embedded in concrete. Replacement of the existing concrete compounds like fly ash, admixtures with bacterial spores which doesn't affect the final properties of mix.

### 3.1 LOW MAINTENANCE COST

- Initial cost of conventional concrete is less compared with bio concrete, but maintenance cost over the age of structures is significantly greater in conventional concrete whereas self-healing concrete costs significantly low in maintenance. Shows fig6: (a) and (b)

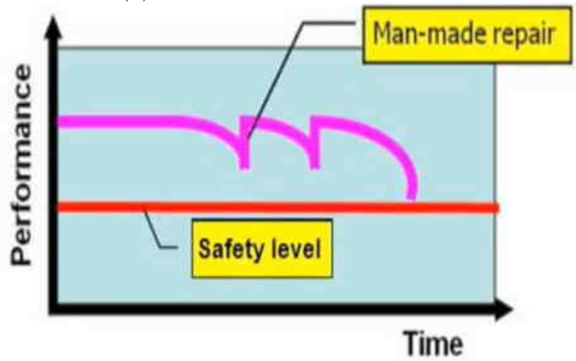


Fig6: (a) conventional concrete

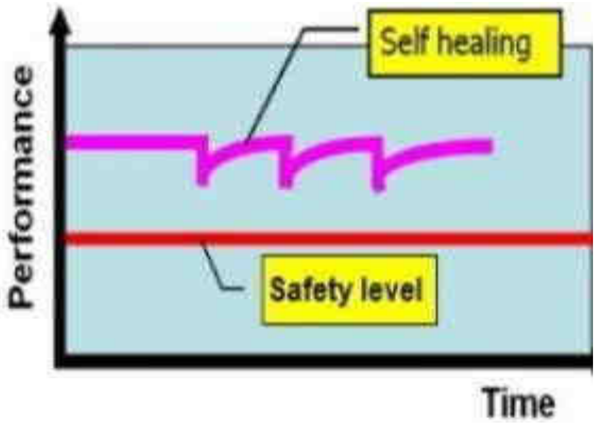


Fig6: (b) self-healing concrete

- Self-healing of cracks by lime (calcium lactate) it eventually increases the service life of structure, which shows that the usage of bio concrete is economical in future perspective.
- Low-cost batch preparation of self-healing agents is a perquisite for the application of microbial selfhealing concrete. [13]

### 3.2 SELF REPAIR AFFECTS

- The repair effect of the crack is also related to the velocity of water flow in the crack. If the flow rate is too high, some of the bacteria and their induced precipitation may be washed away. On the other hand, the calcium carbonate induced by bacteria possessed some different chemical profiles. It has certain gelling property, and also used to consolidate sand [14]. Thus, the precipitation will not be washed out completely, most of the precipitation is still trapped in the crack. However, methods still need to be developed to reduce selfhealing products loss.[15]

### 3.3 FACTOR OF SAFETY

The cost of self-healing concrete compared to conventional concrete still high even with using nanomaterials. Thus, selfhealing concrete is a probable product for several civil engineering structures where the concrete cost is much higher due to better quality.[16]

For instance, in tunnel linings and marine structures wherein the security is a major issue or in structures in which there is limited accessibility for repairing and maintaining. In such special circumstances, even if the self-healing agents incorporated concretes cost higher it should not be too burdensome looking at the safety and future benefits. [16]

## IV. SUSTAINABLE DESIGN OF STRUCTURES

### 4.1 HYDRAULIC ENVIRONMENT

Some of the modern engineering project like bridges, tunnels and water retaining structures are under hydraulic pressure due to water bodies which leads to cracks, corrosion as water percolates inside the concrete and damages the structure, therefore adaptation of self-healing concrete was able to reduce the chloride concentration in a cracked zone by 75% or more.

Service life of self-healing concrete in marine environments could amount to 60–94 years as opposed to only 7 years for ordinary (cracked) concrete. However, life cycle assessment calculations indicated important environmental benefits (56–75%) and mainly induced by the achievable service life extension.[16]

### 4.2 SMART CONCRETE

With recent advancements in concrete technology the bio concrete can be associated as smart concrete, as we know Low carbon emission and energy saving building material incorporated with smart material (in self-healing technology) is a well-known candidate energy technology in enhancing energy efficiency and sustainability of building. The major aim of sustainable development is to keep livelihood on earth in the predictable future with absolute support or care so that ecological balance is not disturbed [17].

Sustainability is founded on three basic elements such as the economic security, environmental safety and societal benefits.

Sustainable advancement must preserve these factors to protect the biodiversity with balanced ecosystem. In the present industrial uprising era, engineers, scientists, policymakers and architects are attempting to use resourcefully the sustainable model to reduce the negative impact on our ecosystem. Therefore, in the perspective of building materials the phrase sustainability used synonymously with robust or friendly and green environment [18,19]. In this viewpoint, self-healing materials have attracted increasing interest due to their potential to lessen the degradation, prolong the functional lifespan, and suppress the maintenance costs of materials [20,21].

However, the self-healing technology contributions directly to enhance the environment and reduction the pollution from increasing concrete life-span and reduction the demand and consumed of OPC as well ‘as affecting to saving energy and increase the sustainability of concrete.[16]

4.3 ECO FRIENDLY MATERIALS

Commonly, gaseous CO2 is released from OPC concrete during the cement clinker's de-carbonation of lime and calcination reactions. Using nanomaterials based selfhealing technology emission of CO2 can remarkably be reduced. Currently, world's development exclusive of concrete is beyond imagination [22]

History tells us that without concrete the wonderful structures like Sydney Opera House, the Chrysler Building, or Taj Mahal could not have existed. Furthermore, the skyscrapers in metropolis all over the world would have reached to such striking altitudes without the usage of celebrated concretes. Moreover, the production of OPC (primary concrete binder) adds to over 5% of the totally released greenhouse gases annually worldwide. It leads to environmental degradation and enforces threat to our environment where world development is striving for sustainable and green building deployment [23]

Therefore, the future aim is targeted to build cleaner, safer, efficient, reliable, and stronger smart materials alternative to concrete than the conventional OPC based concretes.as well as the reduction of CO2 will eventually leads to control of global warming and climate change. In this spirit, the notion of nanomaterials based smart concrete and self-healing technology has been coined.[16]

FUTURE APPLICATIONS OF BIO CONCRETE:

- Global self-healing concrete market size is expected to reach $1,375,088.0 thousand by 2025, from $216,720.0 thousand in 2017, growing at a CAGR of 26.4% during the forecast period from 2018 to 2025.
- Countries such as India, China and Japan have huge potential to provide the required momentum for the market growth in the Asia-Pacific region due to significant presence of huge construction and multiple research projects in the region
- The civil infrastructure is expected to be the highest beneficiary of using self-healing concrete, which will improve the application base.

CONCLUSIONS:

This review paper concludes:

- By the research over self-healing concrete we can say that it helps in saving maintenance cost and increasing the life of structures which ensure ample opportunities in market.
- This paper will motivate young researchers to discover the substitute species of bacterial agents suitable for use in preparation of concrete mix, which can eventually make it cost effective and economical for large scale production in construction industry.
- Bio concrete gives reliable and durable construction, which is perquisite in roads, dams, tunnels and water retaining structures hence it also provides greater factor of safety.
- In addition, rise in need for preserving the infrastructure also supplements the self-healing concrete market growth. Moreover, growth in building and construction industry increases the demand for self-healing concretes across the geographies.
- By adapatability of bio concrete the reduction in emissions of CO2 can be achieved which leads to control of global warming and climate change, gradual move towards the sustainable designs of structures.

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