An Experimental Analysis on Bio Concrete with Bentonite as Partial Replacement for Cement

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Abstract : The concrete is the composite material made by the combination of the cement, sand, coarse aggregate and water. It is versatile in nature and can be cast in diverse shape hence it is used in major part of the construction industry. But the major disadvantage of the concrete is the Co2 emission, which will cause pollution to the environment. In order to control this emission to the environment the Bacillus bacteria is added to the concrete, which will absorb Co2 and undergo Bio-mineralization of Caco3.In this project an attempt is made to study the strength of bacterial concrete. To enhance the strength more, Bentonite powder is added as a replacement of 0%, 5%, 7.5% and 10% to the cement. Bentonite has strong colloidal property and which volume increases several times when coming in contact with water, creating a gelatinous and viscous fluid. The bacteria is added along with CaO which can precipitate calcite in crack and with that make the concrete structure water tight and enhance durability. This reduces the pores or cracks present in the concrete thus increasing the strength of the concrete.

2. Introduction

Cement concrete is one of the most widely used materials for construction works in the field of civil engineering. This is mainly due to low cost of materials and construction, for concrete structures as well as low cost of maintenance. Concrete has a large load bearing capacity for compression load, but the material is weak in tension. Because of this steel reinforcement is provided and the steel bars take over the load when the concrete cracks in tension. However, the cracks in the concrete pose a problem. Due to reasons like freeze-thaw reactions, shrinkage, low tensile strength of concrete etc., cracks occur during the process of concrete hardening and this ultimately leads to weakening of the buildings. If water droplets enter into the concrete structure, due to lack of permeability then it can damage the steel reinforcement present in the concrete member.

When this phenomenon occurs, the strength of the concrete decreases and which results in the decay of structure. Synthetic materials like epoxies are used to remediate, but they are costly, not compatible and need constant maintenance. Using chemicals is also causing damage to the environment. The need for an environment friendly and effective alternate crack remediation technique leads to the development of using the bio mineralization method in concrete.

Here we are incorporating calcite precipitating bacteria to concrete in certain concentrations so that the bacteria will precipitate calcium carbonate when it comes in contact with water and this precipitate will heal the cracks. Micro biologically Induced Calcite Precipitation (MICP) is the process behind bio mineralization. The basic principle in the process is that the microbial urease, hydrolyzes urea, to produce ammonia and carbon dioxide and the ammonia released in surroundings subsequently increases the pH, leading to accumulation of insoluble calcium carbonate. Thus, this self-healing and lesser porosity system can achieve a tremendous cost reduction in terms of health monitoring, damage detection and maintenance of concrete structures, assuring a safe service life of the structure.

Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specially selected types of bacteria genus, bacillus, along with calcium based nutrient known as calcium lactate and nitrogen and phosphorous are added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years. However, when a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria, germinate on contact with water and nutrients. Having been activated, the bacteria start to feed on the calcium lactate. As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. As the oxygen is consumed by bacteria in the process, it prevents corrosion of the embedded reinforcement and thus the durability of the steel increases. On the surface of control concrete, Calcium Carbonate will be formed due to the reaction of CO_2 present with Calcium Hydroxide present in the concrete matrix according to the following reaction:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H2O$$

As $Ca(OH)_2$ is a soluble mineral, it gets dissolved in entering water and diffuse out of the crack in the form of leaching. The self-healing process in bacteria incorporated concrete is much more efficient due to the active metabolic conversion of Calcium nutrients by the bacteria present in concrete:

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

Here Calcium Carbonate is produced directly due to microbial metabolic process and also indirectly due to autogenously healing. This process results in efficient bacteria-based crack sealing mechanism.

2. Literature review

Sakina Najmuddin Saifeeet.al published a paper on Critical appraisal on Bacterial Concrete. In this paper they discussed about the different types of bacteria and their applications. The bacterial concrete is very much useful in increasing the durability of cementious materials, repair of limestone monuments, sealing of concrete cracks to highly durable cracks etc. It also useful for construction of low cost durable roads, high strength buildings with more bearing capacity, erosion prevention of loose sands and low cost durable houses. They have also briefed about the working principle of bacterial concrete as a repair material. It was also observed in the study that the metabolic activities in the microorganisms taking place inside the concrete results into increasing the overall performance of concrete including its compressive strength. This study also explains the chemical process to remediate cracks.

Rajesh Talluri, Prathap Mathangi, Venkatesh warlu Musini (2015): From the study we can predict that the lifetime of bacterial concrete is more than conventional concrete. So, the use of bacterial concrete can create new job opportunities for the experts. When bacterial concrete is completely developed, it may become yet another alternative method to replace OPC and its dangerous effect on environmental pollution result in the crack sealing. Hence can be used for construction as it is resistant to corrosion. There are many advantages of bacterial concrete, it primarily reduce the maintenance costs, repair costs and hence results in increase of durability of the structures. Bacterial concrete is useful for water retaining structures. Cracks can be filled by self-healing technique and leakage can be stopped. Especially in underground structures were repair is difficult or impossible, bacterial concrete has a big future. The cost of the bacterial concrete, according to the opinions of researchers is nearly 30% more than the conventional concrete, depending upon the type and concentration of bacteria. But the maintenance cost of bacterial concrete will be very less when compared to conventional concrete.

C.Venkata Siva Rama Prasad, Dr. T.V.S.Vara Lakshmi (2018): From the experimental work carried out on bacterial concrete mixes, following conclusions were drawn: The cantabro loss i.e. abrasion resistance of bacterial concrete mixes is strongly influenced the flexural strength. The flexural strength and cantabro loss are good at 10% of bacteria in bacterial concrete mixes. The flexural strength values are increased and cantabro loss is decreased up to 10% of bacteria in bacterial concrete mixes. The addition of bacteria in concrete has significantly improved the cantabro loss and flexural strength at all ages

Shweta Puri , Manish Bhutani (2016) in this paper the investigation revealed that, as the partial replacement of cement by bentonite and coarse aggregates by recycled coarse aggregates in concrete mix increases, the workability of concrete mix decreases. The partial replacement of cement by bentonite at 10% and coarse aggregate by recycled coarse aggregates at 30% in concrete mix results in increase of compressive strength as compared to controlled mix whereas further replacement of cement with bentonite at 15% and coarse aggregates with recycled coarse aggregates at 45% decreases the compressive strength. The maximum increase in compressive strength was found when partial replacement of cement with bentonite at 10% and partial replacement of natural coarse aggregates with recycled coarse aggregates at 30% was 26.78Mpa for seven days 38.93Mpa for 28 days and 42.01Mpa for 56 days. Partial replacement of cement and coarse aggregates by bentonite and recycle coarse aggregate in concrete mix results in marginal increase of split tensile strength at 10% and 30% replacement as compared to control mix. The partial replacement of cement with bentonite at 10% and coarse aggregate with recycled coarse aggregate at 30% in concrete mix results in similar flexural strength as compared to control mix .from the SEM images of concrete containing 10% bentonite as partial replacement and 30% recycled aggregate as partial replacement of natural aggregate, very dense compact and continuous C-S-H gel formation over the entire image is observed resulting in the improved strength.

Kevin Paine: The paper commenced with a discussion of the effects of setting and hardening of concrete and how this affects the way in which self-healing agents must be added to the concrete. In particular, the necessity for encapsulation of the spores and of the medium, in order to counter effects of concrete hardening on the spores and eliminate any effects of the precursor and additional nutrients on the fresh and early-age properties of concrete. The germination and growth of bacteria and the precipitation of calcite are known to be affected by temperature and humidity, and consequently the role of these parameters was discussed. Furthermore, as concrete ages it tends to carbonate and this leads to a loss of pH – from around 14 in the first few hours to potentially as low as 6.5 in the long-term. The significance of the carbonation on the ability of bacteria-healing to take place and the consequences for selection of bacteria was described. One potential advantage of bacteria-healing over other self-healing systems is that it is renewable as the bacteria may sporulate after healing and be available for future healing. This is useful in dynamic systems. The requirements for ensuring sporulation takes place were discussed; in addition to methodologies for re-supplying the bacteria with essential nutrients and medium should these be consumed. Finally, the paper ended with a discussion of the ability of bacteria to heal large cracks, and describes techniques being considered in UK research to utilize bacteria-healing as part of a multi-scale healing system.

B. Dileep Kumar Reddy, Shaik Salma, Petluru Venkata Sai Krishna Chaitanya, K. Mounika (2017): The compressive strength was found to increase with bacterial addition and this increase is mainly due to deposition of microbial induced calcium carbonate precipitation on the microorganism cell surfaces and within the pores of the mortar. It was noticed that in normal mortar, the compressive strength was increased with the increase in bacterial cell concentration up to 106 cells/ml. Maximum increase in compressive strengths was achieved at 106 cells/ml. The percentage increase in compressive strength of 45ml and 60ml bacterial concrete using B. Subtilis for 7 days is higher than conventional concrete.

3. Experiential Materials

a) Cement

Fig 1 Cement

Ordinary Pozzolana Cement (53 grade) conforming to IS: 12269 -1987 and with the specific gravity 3.15 was used for casting all the specimens. Tests conducted on cement are fineness of cement by sieve analysis (using 90 µ sieve), specific gravity using Le-chatlier's apparatus, initial setting time and final setting time using vicat apparatus.

Property of Cement	Values
Fineness Of Cement	4.93
Grade Of Cement	53
Specific Gravity	3.19
Initial Setting time	35 minutes
Final Setting Time	588 minutes

Table 1. Properties of cement

b) Fine aggregate

Fig 2 Fine Aggregate

Clean and dry manufactured sand (M- sand) available locally was used. M- Sand passing through IS 4.75 mm sieve and as per IS: 383-1970 was used for all the specimens. Test conducted on fine aggregate are specific gravity using pycnometer, fineness modulus by sieve analysis.

Properties	Values
Specific Gravity	2.74
Fineness Modulus	4.316

Table 2. Properties of Fine Aggregate

c) Coarse aggregate

Fig 3 Course Aggregate

Crushed granite aggregate with specific gravity of 2.6 and passing through 20 mm sieve and retained on 12.5 mm sieve and as given in IS: 383 - 1970 is used for all the specimens

Properties	Values
Specific Gravity	2.80
Size Of Aggregates	20 mm
Fineness Modulus	3.5

Table 3. Properties of Coarse Aggregate

d) Water

Casting and curing of specimens were done with the potable water as per IS 456:2000. The test results are compiled as table 4

WATER	pH VALUE
Sample 1	7.1
Sample 2	7.4
Sample 3	6.9

Table 4. pH Value Test

e) Bentonite

Fig 4 Bentonite

Bentonite is the clay generated from the alteration of volcanic ash. It is used as a partial replacement of fine aggregate. This aggregate has a specific gravity of 1.10 to 1.40.

f) Bacteria

The bacterium used in this concrete is Bacillus subtilis. The concentration of this bacteria is about 2*10^7. This bacterium is found in soil and gastrointestinal tract of ruminants and humans.

g) Super plasticizer

A substance which imparts very high workability with a large decrease in water content (at least 20%) for a given workability. A high range water reducing admixture (HRWRA) is also referred as Super plasticizer, which is capable of reducing water content by about 20 to 40 percent has been developed. The effect of Super plasticizers lasts only for 30to 60 minutes, depending on composition and dosage and is followed by rapid loss in workability. Super plasticizers are added to reduce the water requirement by 15 to 20%.

4. Results and discussion

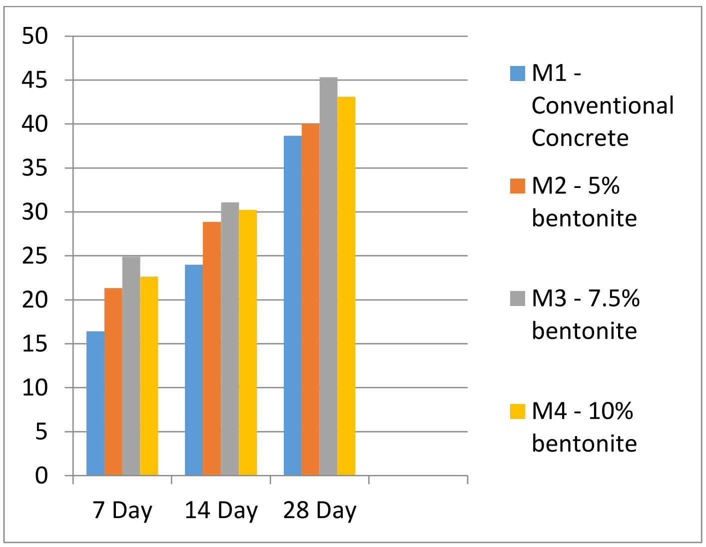
a) Compressive strength test

The compressive strength test was carried out on 150mm x 150mm x 150mm cubes as specified by IS 516-1959(1989). The results of the compressive strength of conventional and bio concrete with bentonite as partial replacement for cement at 7 days, 14 days and 28 days for M50 grade concrete are tabulated.

Fig 5 Compressive strength test

S. No.	Name of the specimen	% of Bentonite replacement	Compressive strength (N/mm^2)		
			7 Days	14 Days	28 Days
1.	M1	0	22.14	25.1	34.0
2.	M2	5	23.4	26.32	35.37
3.	M3	7.5	24.56	27.63	36.29
4.	M4	10	22.52	24.88	34.5

Table 5. Compressive Strength of Conventional Concrete and Bio Concrete – 7, 14, 28 days



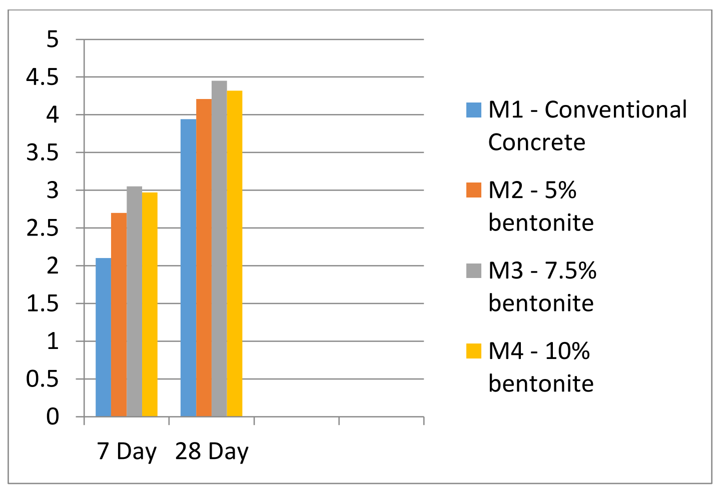
b) Split tensile strength

The split tensile strength is the indirect measurement of the tensile strength by placing a cylindrical specimen horizontally between the loading surfaces. This method consists of applying a diametric compressive force along the length of a cylindrical specimen. This loading includes tensile stresses on the plane containing the applied load. Tensile failure occurs rather than compressive failure. Plywood strips are used so that the load is applied uniformly along the length of the cylinder and the load is applied until failure of the cylinder, along the vertical diameter. The maximum load is divided by appropriate geometrical factors to obtain the splitting tensile strength of concrete. The results of the split tensile strength of conventional and Bio concrete with partial replacement of cement and bentonite at 7 days and 28 days for M50 grade concrete are tabulated.

Fig 6 Split tensile strength

S. No.	Name of the specimen	% of Bentonite replacement	Split Tensile strength (N/mm^2)	
			7 Days	28 Days
1.	M1	0	2.10	3.94
2.	M2	5	2.70	4.21
3.	M3	7.5	3.05	4.45
4.	M4	10	2.97	4.32

Table 6. Split Tensile Strength of Conventional Concrete and Bio Concrete – 7 days & 28 days`

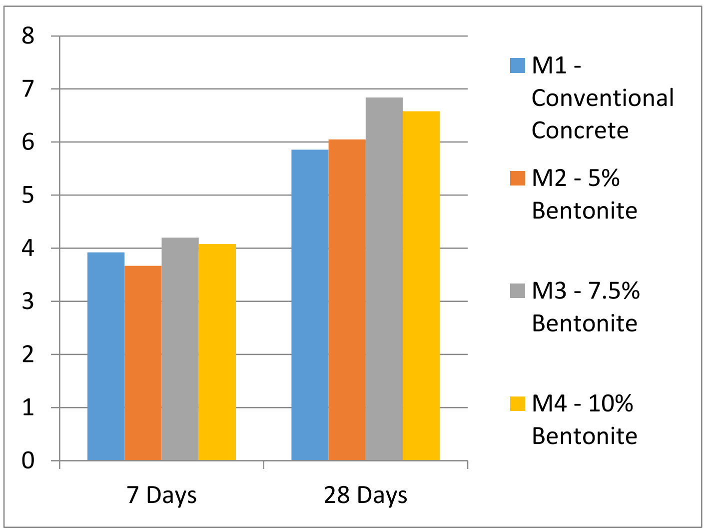


c) Flexural strength test

For each of the different dosages, three prisms with the dimensions of 100 × 100 × 500 mm concrete were prepared. Prisms were de-moulded after one day and immersed in the water tank for a period of 28 days to assure adequate curing. After 7 days and 28 days, prism was tested under flexure using the four point loading test setup.

Table7. Flexural Strength of Conventional Concrete and Bio Concrete – 7days & 28 days`

S. No	Name of the specimen	% of Bentonite replacement	Flexural strength (N/mm^2)	
			7 Days	28 Days
1.	M1	0	3.92	5.86
2.	M2	5	3.67	6.05
3.	M3	7.5	4.20	6.84
4.	M4	10	4.08	6.58



CONCLUSIONS

The present work investigated the physical and chemical properties of bio concrete. Concrete properties were analyzed with bentonite as partial replacement of cement (5%, 7.5% and 30%). On the basis of the results from the present study, following conclusions are drawn.

Based on the test carried out on the three mixtures the following conclusion has been made:

- The Experimental study shows that the Concrete mixed with Bacillus Bacteria and Bentonite as partial replacement of cement increases the compressive strength of the concrete which is cast and cured for 28 days.
- The bacteria produced from laboratory are proved to be safe and economical and it is mixed with CaCO3.
- The use of bacteria in concrete enhances the strength of the concrete hence using this bacterium for self-healing mechanisms also.
- It has been found that the compressive strength of concrete with 7.5% partial replacement of bentonite shows better results when compared to cement with 5% and 10% partial replacement of bentonite.
- The study accomplishes that the use of bacteria (Bacillus Subtilis) in concrete enhances its strength and durability hence using this type of bacteria for self-healing mechanism in concrete can produce cost effective strong or durable structures

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