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Development of an Innovative Material For Structural Application Using Bacteria

[1]R.Vasanthi and [2]Dr.R.Baskar

[1]*Professor & Head, Department of Civil Engineering, Kongunadu College of Engineering and Technology, Thottiyam, Tamil Nadu*
[2]*Professor, Department of Civil Engineering, Annamalai University, Annamalai Nagar, Chidambaram, Tamilnadu, India*

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ABSTRACT

Cracks in the concrete are an insolvable problem around the world. Cracks in the structure reduce the strength and durability of the concrete. Cracks caused in the structure due to over load on the structure than that of the designed load, shrinkage in the concrete surface, voids present in the concrete and permeability. The aggressive gas or water penetrates in to the concrete. Due to the reason inside of the structure get damaged. Various types of bacteria are available in earth it may be harmless or harmful of the human and it also causes diseases to the human. But some kinds of bacteria will be used in construction of a structure. By using bacteria in the concrete it makes the structure more strength, durability, reduce permeability and prevent the corrosion. The bacteria will produce glue or gel. The glue is a natural adhesive material and it is very strong and the bacteria will stay in one place for a long period. Using of this glue it will fill (or) seal the crack (or) pores in the concrete structure. Different types of bacteria are used to make the crack free concrete i.e., Bacillus elaterium, Bacteria filla, subtilus etc.,Thus bacteria activate three cells which produce calcium carbonate, filamentous to act reinforcing fiber, and levans glue which act as binding agent. The calcium carbonate and levans glue combining with filamentous cell make hardening to the same strength achieved to the surrounding concrete. When bacteria will be introduced in mixing of the concrete with nutrient or food (yeast, mineral and urea) the bacterial precipitate glue (or) calcite, the glue seal the cracks it improves the compressive strength, flexural strength and reduce the permeability. While the bacteria used in the concrete it also reduce the cost of maintenance and it will increase the life of the structure. To feed nutrient while mixing the concrete it grows and spread it produce the strongest glue inside the concrete. When the water seep through the crack the bacteria immediately acting to seal the crack and to prevent further damage in the concrete. Also the bacteria activate when it exposure to the air. If there will be any crack formed in the structures the bacteria precipitate the calcite and arrest the crack. Corrosion is the major problem to damage the structure if the oxygen enters through the crack (or) pores due to the bacterial activity it consume the oxygen and prevent the corrosion of the reinforcement. I have studied the previous researchers work and gathered when the bacteria's used in concrete the strength and durability of the concrete increased. I am going to analyses the overall performance of the structure while using the bacteria in the concrete and also the comparison of the cost between normal concrete and bacterial concrete in my research.

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INTRODUCTION

1.1 General:

Concrete is most commonly used building material, but the cracks in concrete create problem. Cracks in concrete occur due to various mechanisms such as shrinkage, freeze-thaw reactions and mechanical compressive and tensile forces. Bioengineered self-repairing concrete biologically produces calcium carbonate crystals to seal cracks that appear on the surface of the concrete structures. Specific spore forming bacteria like Bacillus subtilis and Staphylococcus aureus, supplied with a calcium-based nutrient are incorporated in to the concrete suspended in mixing water.

When cracks appear in a concrete structure and water starts to seep in through, the spores of the bacteria starts microbial activities on contact with the water and oxygen. In this process of precipitating calcite crystals through nitrogen cycle the soluble nutrients are is converted to insoluble CaCO3. The CaCO3 solidifies on the crack surface, thereby sealing it up.

The consumption of oxygen during the metabolic biochemical reactions to forms CaCO3 helps in arresting corrosion of steel because the

Corresponding Author: R.Vasanthi, Professor & Head, Department of Civil Engineering, Kongunadu College of Engineering and Technology, Thottiyam, Tamil Nadu, INDIA

oxygen is responsible to initiate the process of corrosion thereby increasing the durability of steel reinforced concrete structures.

1.2 *Application Of Bacteria In Concrete:*

Bacteria are the most abundant and metabolically diverse forms of life on earth. They grow under a wide range of geochemical conditions in an unparalleled variety of habitats. Basically, microbial life exits wherever there is liquid water at temperature from -7º C to about 120 ºC . In the biosphere, bacteria can act as geo-chemical agents, resulting in the concentration of materials. This induces in the formation of special minerals, which constitute an area of research of growing interest known as biomineralization. Prokaryotic microorganisms, or bacteria, are remarkably potent agents of biomineralization too. Use of this biomineralogy concept leads to the potential invention of a new material, Bacterial concrete an inherent and self- repairing biomaterial that can remediate the cracks and fissures in concrete.

Bacteria added to concrete mix in suspension state must meet certain criteria. Concrete is a highly alkaline building material, so bacteria used as self healing agent should be able to survive in this high alkaline environment for long durations and be able to form spores withstanding mechanical forces during concrete mixing.

In the concrete technology laboratory, a bacterial concrete mix is prepared using alkali-resistant soil bacteria bacillus subtilis and staphylococcus aureus, along with nutrients from which the bacteria could potentially produce calcite based bio-minerals.

The Bacterial concrete can be prepared by adding spore forming bacteria in the concrete that are able to continuously precipitate calcite, this process of production of calcite precipitation is called Microbiologically Induced Calcite Precipitation (MICP). Bacteria is used to induce calcite precipitation in concrete. The basic principle for this process is that the microbial urease hydrolyzes urea to produce ammonia and carbon dioxide and the ammonia released in surrounding subsequently increases pH, leading to accumulation of insoluble calcium carbonate. Bacterial cultures improve the strength of cement sand mortar and crack repair on surfaces of concrete structures.

Calcium carbonate precipitation a metabolic process which occurs in some bacteria, has been investigated due to its wide range of scientific and technological implications. Calcite formation by bacillus species is used in making bioconcrete, which can produce calcite precipitates on suitable media supplemented with a calcium source. The basic principles for this application are that the microbial urease hydrolyzes urea to produce ammonia and carbon dioxide and the ammonia released in surroundings subsequently increases pH, leading to accumulation of insoluble calcium carbonate.

2. *Literature Review:*

C. C. Gavimath, *et al* (2012)- studied on concrete-immobilized spores of bacteria may be able to seal cracks by biomineral formation after being revived by water and growth nutrients entering freshly formed cracks, hence the application of bacteria will improve the strength and durability of cement concrete therefore it appears promising field in near future.

P. Ghosh, *et al*(2006)- studied on biomineralogy concept, attempt has been made to develop bioconcrete material incorporating of an enrichment culture of thermophilic and anaerobic bacteria within cement-sand mortar and concrete. The results showed a significant increase in compressive strength both cement-sand mortar and concrete due to development of filler material within the pores of cement sand matrix.

Henk M. jonkers, Arjan thijssen, *et al*(2010)- studied on investigated the potential of bacteria to act as self-healing agent in concrete, i.e. their ability to repair occurring cracks. A specific group of alkali – resistant spore forming bacteria related to the genes bacillus was selected for this purpose.

Henk M. Jonkers & Erik Schlangen(2009)- studied on the development of a new type of bacteria-based self healing concrete appears promising. The concrete-incorporated bacteria can produce copious amounts of minerals which can potentially seal freshly formed cracks.

R. Narayanasamy, *et al* (2010)-studied on innovative technique of utilizing bacteria for remediation of cracks in concrete. Different types of bacteria, their growth medium, concentrations, pH conditions and their behavior in compressive strength and durability for remediation of cracks in concrete are discussed.

M.V. Seshagiri Rao, *et al* (2013)- studied on bacterial concrete has improved microstructure and permeation properties than controlled concrete. Studies showed that bacterial concrete has better acid resistance in aggressive environments.

Virginie wiktor, *et al* (2011)- studied on the enhanced self-healing capacity of bacteria based concrete has been quantified, several other characteristics such as long term durability and cost efficiency of this novel type of concrete needs to be resolved before practical application can be considered.

3. *Objectives:*

The main aim of this research to evaluate strength of cement concrete by using self healing bacteria like bacillus subtilis and staphylococcus aureus.

Investigate the performance of compressive, split tensile and flexural test on specimens like cubes, cylinders and prisms.

Examine the effectiveness of strength of the concrete:

In this project to develop a new type of self-healing concrete in which bacteria mediate the

production of minerals which rapidly seal freshly formed cracks.

A process that concomitantly decreases concrete permeability, and thus better protects embedded steel reinforcement from corrosion.

Further development of this bio-concrete with significantly increased self-healing capacities could represent a new type of durable and sustainable concrete with a wide range of potential applications.

4.1 ***Materials Used:***

4.1.1 ***Cement:***

Portland cement of 43grade available in local market is used in the investigation. The cement used has been tested for various properties as IS: 4031-1988 and found to be confirming to various specifications of IS: 12269-1987 having specific gravity of 3.08.

4.1.2 ***Fine Aggregate:***

Natural river sand well graded passing through 4.75mm sieve was used to find the compressive strength of cement mortar cubes and cylinders.

4.1.3 ***Coarse Aggregate:***

Crushed aggregates of well graded igneous rocks of size 20mm.

4.1.4 ***Water:***

Locally available river water confirming to IS 456 is used.

4.1.5 ***Bacterial Strains:***

Pure cultures were maintained on nutrient agar slants and were preserved under refrigeration until further use, sub-culturing was carried out for every 30 days. Contamination from other bacteria was checked periodically by streaking on nutrient agar plates. Whenever required, few colonies of the pure culture is inoculated into nutrient broth of 25ml in 100ml conical flask and the growth condition are maintained at 370C temperature and placed in 125 rpm orbital shaker.

4.2 ***Types Of Bacteria Used:***

i)Bacillus subtils
ii)Staphylococcus aureus.

4.3 ***Preparation Of Specimens:***

Weigh batching is adopted for casting specimens in the laboratory. The quantity of fine aggregate, coarse aggregate, cement and additives (bacteria's) and water is determined by weight. Then for concrete the properly weighed fine aggregate , coarse aggregate , cement and additives is mixed with their proper ratio's. Tray and trowel are used for proper mixing.The concrete batch is mixed on a following procedure

The cement and fine aggregate is mixed dry until the mixture. The coarse aggregate is added and mixed with the cement and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch.

The Bacillus subtilis and Staphylococcus aureus bacteria of 0.3ml & 0.4ml are separately added with water is mixed until the concrete appears to be homogeneous and has the desired consistency . If repeated mixing is necessary, because of the addition water in increments while adjusting the consistency , the batch is to be discarded and fresh batch is made.

The consistency of M20 and M25 grade concrete mix is designed as per standard design procedure using the properties of materials as discussed and provided in Table .The water-cement ratio used in the design is for M20 is 0.55 & M25 is 0.5. The mix proportion of material comes out to be for M20 is 1:1.8:3.3.5 (cement: sand: aggregate) & M25 is 1:1.6:3.2.

4.4 ***Mixing, Casting And Curing:***

The aggregate were prepared in saturated surface dry condition , and were kept. The fine and coarse aggregate, cement were dry mixed by hand mixing. The liquid part of the mixture, ie., water and bacterial strains are added in aggregates.

The wet mixing usually is in cohesive condition. The workability of the fresh concrete was measured by means of the conventional slump test. The slump measured in the conventional concrete was 60mm for M20 & 55mm for M25 slump.

Compaction of fresh concrete in the cube & cylinders steel mould s was achieved by applying 25 times strokes per layer in three equal layers , followed by compaction on a vibration table for ten seconds . The prepared concrete specimens kept in the moulds. After 24 hours the specimen are demould. The specimens are ordinary curing for 28 days.

No. of days	Conventional concrete (N/mm2)		Adding staphylococcus aureus (N/mm2)			
			M20		M25	
	M20	M25	30ml	40ml	30ml	40ml
7th	15.5	18	20	23	20	22
14th	22	24	21.3	28	26.1	23.6
21st	26	29	27.5	30.2	29.2	31
28th	29	33	29.5	36	34.5	37

Experimental Investigations:

5.1 ***Compressive Test:***

In the case of cubes, the specimens is placed in the machine in such a manner that the load is applied to opposite sides of the cubes at cast. the axis of the specimen is carefully aligned with the center of thrust of the spherically seated plate. No packaging is used between the faces of the specimens and the

steel plate of testing machine . A spherically seated block is brought to bear on the specimens; the movable portion is rotated gently by hand so that uniform seating may be obtained. The load is applied without shock and increased continuously until the specimen to the increasing loads breaks down and no greater load can be sustained. The maximum load to the specimen is then recorded. The results are shown table no 6.1 and 6

Compressive strength = P/A

Where, P = Ultimate load in N

A = Area of the cube in mm2.

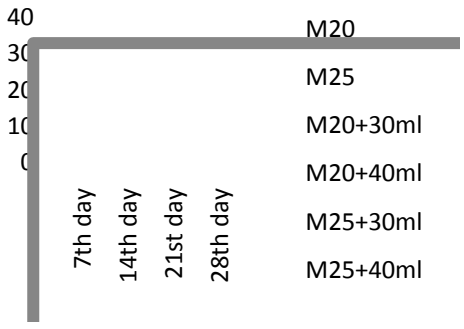
5.1 ***Compressive Strength Test (Cubes:)***

Typical image of compression test setup given below:

Fig.5.1(a):

Fig. 5.1(b):

Bio-Concrete (Bacillus Subtills):



5.2 ***Split Tensile Test:***

The convention and bacterial concrete cylinder specimen after casting were cured for 28 days in the water bath and were tested in compression testing machine as per Indian standards. From the tests, it was observed that, the concrete specimens prepared by incorporating the micro organism yielded higher tensile strength as compared to the conventional concrete.

The split tensile test on the specimens were performed on a 2000 KN Capacity hydraulic machine in accordance to the relevant Indian standards. The 100x200mm concrete cylinders were tested for every split tensile test.

Tensile strength=0.52P/A

Where, P = Ultimate load in N.

A = Area of the cube in mm2.

5.2 ***Split Tensile Test:***

Fig. 5.2(a):

The specimen was tested for flexural strength at an age of 7days, 14 days,21 days curing. The specimen were submerged in clean fresh water in a curing tank and kept there until taken out just prior to test. The size of the specimen is 100mm×100mm×500mm. There specimen were not to be allowed to become dry at any time until they have been tested. The weight of the specimen was noted before testing. Flexural strength at 28 days was found out.

The surface of the UTM was wiped clean the other materials. The support sections should be arranged to the UTM. While placing of the beam in the support section in proper bearings. When the two point load set up should be allowed from the beam support and not it down central deflection of the beam section. The maximum load applied to the specimen was recorded and any usual appearance in crack was noted. The flexural strength of the specimen was calculated by using the formula.

Flexural strength = PL/bd2 N/mm2

Where,

P = Load at which specimen fails in N

L = Effective span in mm

B = Breadth of the specimen in mm

5.2 *Tensile Test (Cylinders):*

No. of days	Conventional concrete (N/mm2)		Adding Bacillus subtils (N/mm2)			
			M20		M25	
	M20	M25	30ml	40ml	30ml	40ml
7th	2.10	2.60	1.89	2.40	2.42	2.71
14th	2.32	2.63	2.25	2.60	2.68	2.90
21st	2.53	2.90	2.43	2.70	3.00	3.29
28th	2.67	3.42	2.90	3.03	3.50	3.62

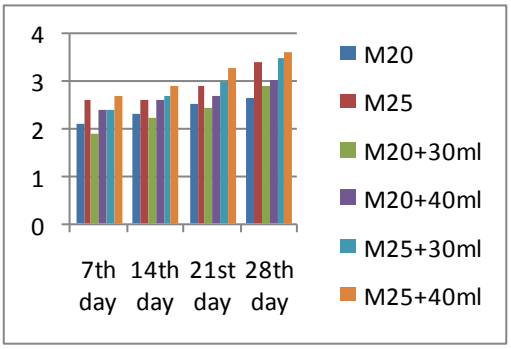


Fig. 5.2: conventional Vs bacillus subtills.

Bio-Concrete (Staphylococcus Aureus):

5.3 *Compressive Strength*:

No. of days	Conventional concrete (N/mm2)		Adding staphylococcus aureus (N/mm2)			
			M20		M25	
	M20	M25	0.3ml	0.4ml	0.3ml	0.4ml
7th	15.5	18	20	23	20	22
14th	22	24	21.3	28	26.1	23.6
21st	26	29	27.5	30.2	29.2	31
28th	29	33	29.5	36	34.5	37

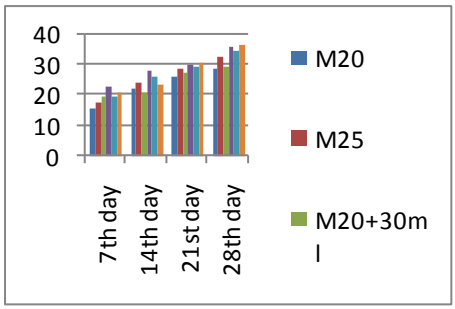


Fig. 5.3: Conventional Vs Staphylococcus aureus.

5.4 Split Tensile Test (Staphylococcus Aureus):

No. of days	Conventional concrete (N/mm2)		Adding staphylococcus aureus (N/mm2)			
			M20		M25	
	M20	M25	0.3ml	0.4ml	0.3ml	0.4ml
7th	2.10	2.60	2.64	2.64	2.98	3.31
14th	2.32	2.63	3.31	3.31	3.51	4.10
21st	2.53	2.90	3.64	3.64	3.97	4.30
28th	2.67	3.42	3.97	4.30	4.76	4.96

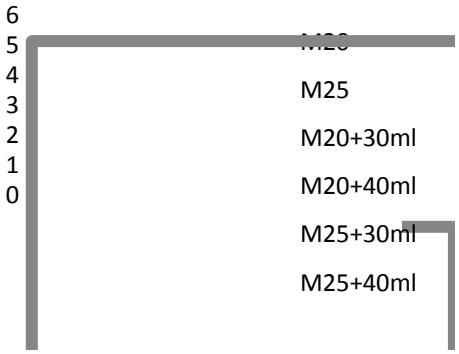


Fig. 5.4: Conventional Vs Staphylococcus aureus.

RESULT AND DISCUSSION

6.1 *Results:*

The cubes and cylinders have been tested as per IS specification. The compressive test and split tensile test were carried out both on conventional and bacterial concrete specimens.

Compressive Strength Test:

The conventional and bacterial concrete cube specimen after casting were cured for 28 days in water bath and were tested in compression testing machine. From the test it was observed that the concrete specimen prepared by incorporating the micro organism yielded higher strength is compared to conventional concrete

The results of the compressive test on conventional and bacterial concrete is indicated in table 5.1 and 5.3. The results of compressive test with and without addition of bacillus subtills and staphylococcus areus show in the table.

Split Tensile Test:

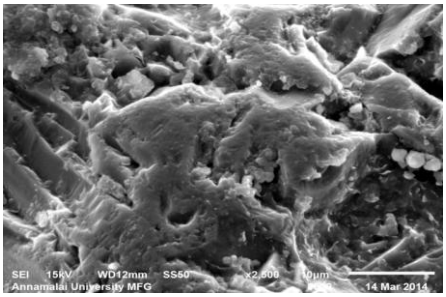
The conventional and bacteria concrete cylinder specimen after casting work cured for 28 days in the water bath and were tested in compression testing machine as per IS. From the test it was observed that the concrete specimen prepared incorporating by micro organism yielded higher tensile strength as per compared to conventional concrete.

The result of split tensile test without addition of bacillus subtills and staphylococcus areus show in the table 5.2 and 5.4

Flexural Test:

The conventional and bacteria concrete prism specimen after casting work cured for 28 days in the water bath and were tested in compression testing machine as per IS. From the test it was observed that the concrete specimen prepared incorporating by micro organism yielded higher tensile strength as per compared to conventional concrete. The result of split tensile test without addition of bacillus subtills and staphylococcus areus show in the table and 5.5

Appentix A:
Sem Analysis:



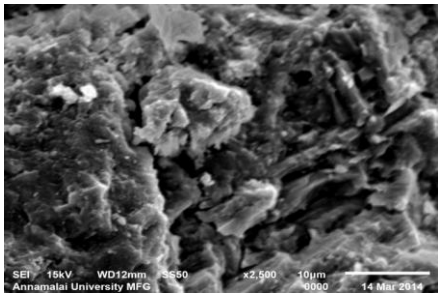
Surface of control paste specimen (7th day).

Water	Cement	Fine aggregate	coarse aggregate
191 lit	347 kg/m³	654 kg/m³	1244 kg/m³
0.55	1	1.88	3.58

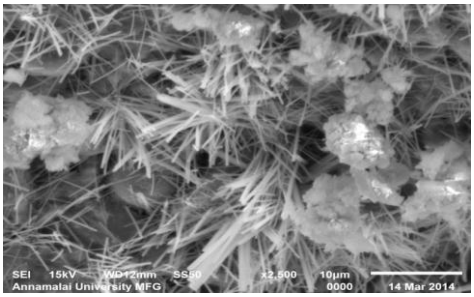
Discussion:

The main objective of the study was to investigate whether bacteria can potentially act as a self healing agent in concrete. The bacteria tested are known to be alkaline resistant i.e they grow natural environmental characteristics by a relatively high pH (10-11). In addition these strains can produce spores which are testing cells with study cell walls that

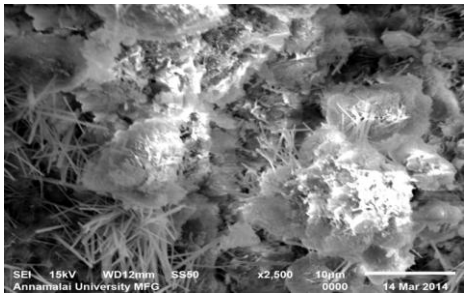
protect from extreme environmental mechanical and chemical stresses. Therefore these specific bacteria may have the potential to resist the high internal concrete pH value (12-13 for Portland cement based concrete) and remain viable for a long time as well as spore viability for up to 200 years is documented. In a dormant (alive but not growing) and viable (capable of working successfully) micro organism certain number is induced in concrete during mixing. Bacteria spores immobilized in the concrete matrix will became metabolically active when reviewed by water and calcium media of concrete. The hollow space (microscopic level) will subsequently the rabidly plugged and sealed through metabolically mediated microbial calcium carbonate precipitation, hampering further ingression of water and other chemicals.



Surface of control paste specimen (28th day).



Calcite particles formation on surface of staphylococcus areus plus calcium lactate enriched specimen (7th day)



Calcite particles formation on surface of staphylococcus areus plus calcium lactate enriched specimen (28th day)

The micro-organism hydrolyze urea to produce ammonia and carbon dioxide, resulting in an increase of pH in the surroundings where ions Ca2+ and CO32- precipitated as CaCO3. Possible bio chemical reactions in media to precipitate CaCO3 at the self surface that provides a nucleation site.

Conclusion:

We conclude that concrete immobilized spores of such bacteria may be able to seal cracks by bio mineral formation after being revived by water and growth nutrients entering freshly formed cracks. Hence the application of bacteria will improve the strength of cement concrete therefore it appears promising field in near futures.

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