INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)

www.ijprems.com
editor@ijprems.com

Vol. 04, Issue 04, April 2024, pp: 1876-1883

e-ISSN : 2583-1062

Impact Factor: 5.725

A SURVEY OF THE BACTERIOLOGICAL SOLUTION FOR CONCRETE CRACKS

Amit Singh Blouria[1], **Er. Rekha Devi**[2]

[1]M. Tech Scholar,Desh Bhagat University Gobindgarh Punjab, India

[2]Assistant Professor, Desh Bhagat University Gobindgarh Punjab, India

ABSTRACT

Concrete, a solid, tough material made out of concrete, totaland water is the most important utilized structure material on the planet. Concrete is extremely capable of sustaining weight under pressure, but it is weak when put under strain.Because of this, steel bars are inserted into the solid to allow buildings to carry ductile loads. When a solid cracks under strain, steel reinforced bars carry the weight.In contrast, the solid prevents consumption by shielding the steel-fortified bars from the ground.In any event, the strength of the constructions is significantly impacted by solid structure breakdowns.Here, water and chloride ions enter the framework and the steel starts to corrode, causing the structure to disintegrate.By adding additional fortification to the structure during the planning stage, it is possible to increase the quality and sturdiness of the structure while ensuring that the break width stays within a reasonable cutoff. The traditional methods for repairing framed splits include epoxy infusion or latex treatment.

Only for sturdiness purposes (to keep the break width narrow) and not as a basic constraint, is this additional support required.Giving more steel is not financially prudent, especially given how much it already costs to produce steel.Primary motivation to forestall breaks or cutoff split width is to upgrade the toughness of the structure. In the event that somehow or another a dependable technique could be built up that fixes splits in concrete consequently (self-recuperating), this would increment and guarantee sturdiness of the structure colossally. Then again it would likewise set aside a great deal of cash, time and vitality. The idea for a reliable organic self-mending method that uses bacterial cement to patch gaps in solid materials was first put forth by V. Ramakrishnan. Bacillus bacterium strain No. JC3 is one potential strategy in the ongoing search for split-free concrete.

There is additional discussion of the difficulties and constraints posed by low-power SRAM design, such as performance deterioration, production variances, and reliability problems. Here are some ideas for overcoming these obstacles without sacrificing energy efficiency.

Key Words: Bacteriological solution, Concrete cracks, Microbial concrete repair, Bacterial strains Bacterial treatment, Concrete durability,Biogenic crack filling

1. INTRODUCTION

Concrete is the most generally utilized development material. In spite of its adaptability in development, it is known to have a few confinements. It is frail in strain, has restricted flexibility and little protection from splitting. In light of the ceaseless examination completed the world over, different changes have been produced usingtime to survive the insufficiencies of concrete. The progressing examine in the ground of solid innovation needs to prompt the advancement of unique cement thinking about the speed of development, the quality of cement, the sturdiness of cement and the natural kind disposition with mechanical physical like fly debris, impact heater slag, silica smolder, metakaolin and so forth.

Recent research has shown that the general performance of cement was enhanced by microbial mineral precipitation caused by the metabolic activities of optimal microorganisms in concrete. The process may take place within, outside, or even a distance inside the solid from the microbial cell. Often, bacterial activities simply cause an adjustment in the science of the arrangement, which leads to over-immersion and mineral precipitation. It is anticipated that a new substance called "Bacterial Concrete" will be produced by applying these biomineralogy principles to solids.

Microbiology

Microorganisms were tiny, prokaryotic, living breathing forms. There are many different forms and sizes of microbes.Microorganisms can be found in every habitat on Earth, growing in soil, radioactive waste, water, corrosive aquifers, and deep below the Continental mantle, as well as in natural disasters and the sentient groupings of creatures and plants.The average concentration of bacteria is 40 million cells per gramme of soil and 1 million cells per millilitre of freshwater.,there isroughly five nonillions (5×1030) microorganisms on continental (Whitmanetal. 1998, Vol.95) framing a great part of the world's biomass.

Louis Pasteur proved on 1859 that bacterial proliferation is now one of the factors contributing to the ageing process. Similar to Robert Koch, one of his colleagues, he was a devoted supporter of genetics as a science.

The gramme positive and gramme negative subtypes of bacteria are the two main varieties of the phone division. The names are taken from how cells respond to the Gram stain, a test that has been around for a while and is used to classify different bacterial species.

ORDER OF BACTERIA

Order of Bacteria - Foundational Shapes

Typically, the morphologies of microorganisms determine their arrangement. They can be broadly divided into three groups: Cocci, which are sphere-shaped germs, and Bacilli, which are rod-shaped microbes (Spirilla).

Order of Bacteria -Grass Strain as a Base

The results of the Gram Staining Method, which uses a specialist to attach to the cell mass of the tiny organisms to determine whether they are Gram-positive or Gram-negative, are what determine this classification.

Order of Bacteria -Based on the Need for Oxygen

This configuration determines the bacterium's need for oxygen for survival. They function both aerobically and anaerobically (using anexternal source of atomic oxygen as an electron acceptor) (Do not utilise sub-atomic oxygen as a terminal electron acceptor).

DifferentBacteria used in Concrete.

a) Bacillus Pasteurii

b) Bacillue Sphaericus

c) Escherichia Coli

d) Bacillus Subtilis (utilised in this study)

What is Bacillus Subtilis

Various bacterial cements were suggested by experts with varied microscopic organisms. Bacillus pasteurii, Bacillus sphaericus, E. coli, and other bacteria are among the several microorganisms used in the product. The Bacillus subtilis strain number JC3 was employed in the current investigation in an effort to conduct the study. The main benefit of implanting microscopic organisms in the solid is that it can continuously hasten the formation of calcite.Microbiologically incited calcite precipitation is the name given to this marvel (MICP). Because of its extensive range of logical and mechanical repercussions, calcium carbonate precipitation has received scientific attention. A lab-refined soil bacteria called Bacillus subtilis JC3 has a focused effect on the toughness and quality of the soil.

WHAT IS BACTERIAL CONCRETE

V. Ramakrishnan. were the ones who initially proposed the concept of bacterial cement. The use of microbiologically induced calcite ($CaCO_3$) precipitation is a novel method for filling cracks and gaps in concrete. The technique known as microbiologically incited calcite precipitation (MICP) falls under the more general category of science known as biomineralization. A typical soil bacteria called Bacillus subtilis JC3 is capable of starting the precipitation of calcite. $CaCO_3$ precisely combined recreated surface cracks gaps in rocks and helped sand solidify to demonstrate its favourable potential as a microbial sealant.

Given that the calcite precipitation caused by microbial activity is both pure and distinctive, microbiologically inspired calcite precipitation is extremely alluring. The method can be used to increase the stiffness and compressive quality of split solid samples. The bacterial solid makes use of microscopic organisms that precipitate calcite. Microbiologically activated calcite precipitation is the phenomenon's official name (MICP).The exploration gathering of Ramakrishnan V and others at the South Dakota School of Mines and Technology, USA, accounts for the pioneering effort to fix concrete with MICP.

The MICP is a tactic that falls under the more comprehensive category of research known as biomineralization.The process by which tiny or live creatures are created from inorganic materials. Calcite can precipitate when Bacillus subtilis JC3, a typical soil bacteria, is present. When used in concrete, Bacillus subtilis JC3 can consistently promote the growth of an additional, incredibly impermeable layer of calcite over the top of the solid layer that was previously present. Encouraged calcite adheres to the solid surface as scales due to its coarse crystalline structure.

The microbially modified mortar and cement has grown to be a major focus of research towards better construction material. The effects of combining a facultative anaerobic underground aquifer bacteria on the microstructure of concrete sand mortar were investigated by Ghoshetal. The microorganism-adjusted mortar (slender area) revealed significant textural distinctions as for the control tests (without microscopic organisms). Ecological filtration electron small views and picture analysis.

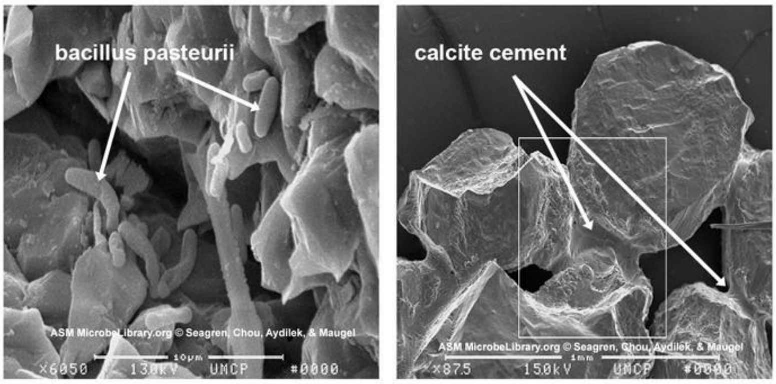


Fig. 1 Amplified picture of Rod-formed impressions reliable with the elements of Bacillus Pasteuriispread around the calcite precious stones.

2. OBJECTIVES

The main objectives are as under:-

- Evaluating the efficacy of bacteriological remedies in mending concrete cracks of different dimensions.
- Assessing the extended resilience and effectiveness in comparison to conventional techniques of mending.
- Examining the ecological consequences and long-term viability of bacteriological solutions in the process of repairing cracks in concrete.
- Evaluating the cost-effectiveness of applying bacteriological remedies for wider adoption.
- Evaluating the compatibility of bacteriological solutions with various concrete compositions and structures.
- Evaluating the resilience of bacteriological solutions to external variables, such as fluctuations in temperature and exposure to chemicals.
- Ensuring the implementation and upkeep of safety and health measures for personnel and the surrounding environment during the process of application and maintenance.
- Identifying potential obstacles and constraints in the implementation of bacteriological treatments for repairing cracks in concrete.
- Evaluating the capacity of bacteriological solutions to be expanded and adapted for use in extensive infrastructure projects and urban settings.
- Investigating novel methodologies and improvements in bacteriological technology to enhance the efficiency and efficacy of concrete crack repair solutions.

3. LITERATURE REVIEW

J.L Gardnerissued a report on a survey of issues with self-remedial mechanisms in concrete building today. The market research study was conducted in the England and it remained discovered that annual costs for the replacement, upkeep, and repair of civil infrastructure projects are enormous. The findings of the bazaarinvestigate confirmed that selfremedial concrete would be able to address some of the major issues with infrastructure for civil engineering. Self-remedial concrete improved durability while lowering overall repair and maintenance costs. Self-remedial cracks, reduced usage of overdesign costs, excess cover to reinforcement, sealing porosity, and prevention of absorption are a few advantages.

E.K Schlangenissued a paper on self-remedial techniques for ensuring the longevity and sustainability of infrastructure. An summary of recent advancements made in self-remedial concrete is provided. Delft University's three ongoing research initiatives on self-remedial mechanisms were discussed. First, bacteria that can precipitate calcite in a fracture and make concrete constructions watertight and more durable are added to concrete. In a second research, SAP mixtureof fibre reinforced resources that can involuntarily patch crashes when they appear are examined.

Senot Sangadji In his study, he explained that concrete cracks when it is under tension and shear. Rebar may become exposed to air and water when a concrete structure develops a continuous network of fissures. Premature concrete building failure and increased raw material usage have been noted. So, it is essential to create a construction that is more durable and long-lasting. A natural approach to attempting this is to include a self-remedial mechanism in concrete or cement. Many different methods are covered, including self-remediation using microbes, self-remediation based on minerals mixtures, and self-remediation based on adhesive agents are examples of autogenous self-remediation.

Willem De Muynck et.al. [4],released an article titled "Bacterial carbonate precipitation enhances cementitious materials durability." The durability of mortar specimens with various levels of porosity is improved by thebacterial carbonate precipitation. Three 100mm X 100mm X 100mm cubes were put through a 28-day test. By placing cubes in a plastic tub and submerging them for 24 hours, B. sphaericus bacteria were introduced. Studies on weight gain and different bio decompositions of bacteria at various depths were conducted.

P.L Krishnapriya a report on isolating and identifying bacteria to increase concrete's strength was published. precipitation of calcite Alkaline soil samples from a cement industry were used to isolate bacterial stains. By using 16SrRNA gene sequencing, three isolates were chosen and recognised. These were recognized as Bacillus flexus Bacillus licheniformis and Bacillus megaterium BSKAU.

Monishaa and Mrs.S.Nishanthi Polyethylene fibre and Bacillus subtilis were used to study the strength of concrete. Dissimilarmicrobial cell attentions of 101, 102, and 103 cells per ml of water are used to make M20 grade concrete, and polyethylene fibre is added at a constant 0.4%. Researchers have examined and contrasted control concrete with selfremedial concrete that uses Bacillius subtilis and polyethylene fibre for strength and durability.

Vijeth N Kashyap, Radhakrishna.Investigated the impact of the bacteria Bacillus Sphaericus and Sporosarcina Pastuerii on cement concrete. After conducting an investigational examination, it remained discovered that these microbes boosted the strength of cement composites by roughly 35.9% and 34.05% in paste when added at 106 concentration of cells/ml of water. For concrete, Bacillus sphaericus and Sporosarcina pastuerii showed respective strength increases of 18.3% and 12.2%. It was determined that stains from Bacillus Sphaericus and Sporosarcina Pastuerii can enhance the properties of cement mixtures because microbially generated calcite rainfall occurs exclusivepastecompoundsamples.

G Lakshmipublished.give a report on the self-remedial properties of bacterially permeatedconcrete and its durability. By incorporating the bacteria Bacillus subtilis JC3 into the concrete prior to curing, this research demonstrates the results that bacterially impregnated concrete is corrosion and crack free. Bacillus subtilis bacteria can survive in the harsh environment of concrete. The thick wall membrane of B. subtilis contributes to their resilience to high pH. As a result, these bacteria slumber in the concrete for 200 years before finding the right environment. Findings indicate that on a 100-day durability test, a crack with a width of 0.1 mm entirely healed, proving that bacterial concrete is more dense and strong.

Mayur Shantilal.discussed the taxonomy and sorts of bacteria, as well as the chemical method used by bacteria to mend cracks. They also discussed the benefits of bacteria in concrete for repairing cracks, increasing strength by lowering permeability, preventing corrosion, and greater resistance to cold and thawing activity. Yet, one drawback of bacterial concrete is that it costs twice as much as regular concrete. There is no design mix for concrete including bacteria in the IS code or any other code. It costs money to research calcite precipitation.

4. METHODOLOGY

GENERAL

The primary objective of current test assessments to get explicit exploratory data that aids in comprehending bacterial cement and its properties (Strength and Durability). The conduct of new and solidified characteristics of normal evaluation concrete,standard grade concrete both the expansion of bacteria has been taken into consideration in the current test examination. By directing reasonable research centre tests on solidified concrete, certain solidified properties, such as the compressive qualityconcrete mortar, the compressive quality,split elasticity of solid, the stress-strain conduct of cement, the flexural conduct of cement, and the toughness parts of cement, are determined.

EXPERIMENTAL PROGRAMME

1. Phase 1= Microbes culture
2. Microbes growth
3. Phase 2= Strength languages
4. Compressive quality mortar shapes in concrete
5. Put the compressive quality and split rigidity of cement into consideration
6. Examine the cement's stressstrain .
7. Consider cement's flexible conduct
8. Phase 3 – Durability

9. Contemplate strength misfortune, weight reduction, acid durabilityand acid attack factors
10.Quickened erosion breaking concrete

Properties and utilized material

Cement

The test uses 53 standard Portland concrete evaluations that are available in local advertisements. All of the experiments' concrete comes from the same clump. The concrete was tested for various qualities in accordance with Seems to be: 4031 to 1988 ,was adapting to various details IS.code :12269-1987.

Ennore sand

According to BIS conclusions, Ennore sand is utilized to determine compressive quality of 3D concrete mortar shapes.

Coarse aggregate

As coarse total, crushed exact rock from a local mine is used. The thoroughly clean coarse total is chosen and tested for several characteristics, including explicit gravity, fineness modulus, mass modulus, and so forth. Physical attributes are tested in accordance with IS.code: 2386 - 1963.

Fine aggregate

In the present study, the locally available river sand is used as a fine total. According to IS.code: 2386-1963, the purified fine total is selected and tested for various parameters, including explicit gravity, fineness modulus, mass modulus, and so on.

Water

Water is intended for mixing and relaxing and is new consumable water according to section 22 and 23 of IS.code:3025 - 1964 and IS.code:456 - 2000.

Bacteria

A refined bacteria from a research facility is used.

Mixed design

Blend configuration is the process of selecting reasonable cement components, such as concrete, as well as water, and determining their relative proportions with the goal of producing cement with the least amount of required quality, functionality, and solidity while still being as cost-effective as is reasonable under the circumstances. The definitions mentioned above reveal two-overlap as the basis for structuring.To achieve the stated least quality and strength is the main goal. Making the solid as effectively as possible is the next objective.

Concrete Mixture

The electrically operated blender completes the blending process. The material like coarse,fine aggregate and cementations material were arranged in orderly layers, one on top of the other. To get uniform shading, one uses dry blending. Alongside the water comes the necessary amount of microscopic organisms (Bacillus subtilis JC3). Using a compaction calculation measuring machine in compliance with IS.code:10510-1983, the functioning tests are performed after the solid has been mixed. phase1, 4.5 The initial phase of the investigation to culture the bacteria is complete.

Stage -1

Bacterial growth:

The JNTUH soil sample was isolated from the culture broth, which is now being kept alive on supplement Agar incline. On a second Agar plate, it arranges the erratic dry white states. The development conditions are kept at 370 °C and placed in an orbital shaker that spins at 125 rpm. When necessary, a single area of the way of life is immunised into a supplement stock of 25 ml in a cup with a funnel shape that contains 100 ml. 4.5.2Dendrogram outlining strain JC3's phylogenetic relationships within Bacillaceae as determined byrRNA 16S quality arrangement analysing.PHYLIP package's highest extreme probability programmewas used to create the dendrogram. Hubs use bootstrap esteems for their numbers. Under50 bootstrap values are removed from the dendrogram. 100% succession resemblance between strain JC3 and Bacillus subtilis has been shown.

STAGE – 2

The investigation's second phase is used to examine the strength behaviour bacterial concrete.

Examinecomprehensive strength cement mortar

The assessment is conducted to take concrete mortar quality into account. 45 different 3D form combinations in all have been cast in an effort to take hub pressure into consideration.

SPECIMEN ARRANGEMENT

According to IS: 4031(Part 6)-2000, standard cubes measuring 70.7x 70.7x 70.7mm were cast. Ratio of cement to sand is 1:3 (weight). The required quantity of microorganisms (104 , 105 , 106 , and 107 cells per ml of adding water) is mixed with media to form cement, sand paste.The specimens were all water-cured.

TESTING SYSTEM

The testing was completed in accordance with IS 516-2000.Once When the required amount of period has elapsed, the blocks are taken out of the treatment chamber and their capacity for compression is assessed. On the broken sample of the (28-day cube sample, a scanning electron microscopy study is used to assess the compressive strength of the mortar cubes at three, seven, and twenty-eight days.

Examinecompressive strength and split tensile strength concrete

The analysis was finished taking cement's split elasticity and compressive quality into account. In total, 32 solid form arrangements are cast in an effort to think about compressive quality under pivotal pressure, and 16 chamber arrangements are cast in an effort to think about split elasticity.

SPECIMEN ARRANGEMENT

Arrangement of samples According to IS 516-1999, 100x100x 100 mm forms are created or assigned a function in ordinary assessment concrete and standard grade solid structure mix. The throw also has 150mm x 300mm chambers. Incorporating both microscopic organisms and no bacteria, the 3D squares and chambers are tossed. The examples are immediately lowered into the relieving tank's free freshwater after being thrown, after which they are demolded after 24 hours. The examples are taken and kept in a shaded area after the restoration period has expired.

Testing system

After the required amount of restoration time, the 3D shape examples are ejected from the relieving tank and cleaned. Numerous forms are tested for compressive quality across time periods of 7 days, 14 days, 28 days, 60 days, 90 days, 180 days, 270 days, and 365 days. At 28 days, 60 days, 90 days, and 180 days, chambers are tested for split rigidity.

Examine stress strain behavior

Examining cement under pressure is done to consider how cement will behave under pressure. 48 chambers are thrown in total, and several of those chambers are tested after 28, 60, 90, and 180days.

Specimen arrangement

Test samples are hollow, circular, and measure 150 mm width and 300 mm height.Moulds are first cleaned and oiled up. Layers of the solid are put to the moulds, and it is totally condensed using a 25mm nail vibrator. Moulds are demolded, covered with concrete mortar, and then restored in a relieving tank after a 24-hour throwing time. After the necessary length of restoration time, the examples are withdrawn from the relieving tank, the moisture is extracted, and the surface is dried.

TESTING SYSTEM

The example at the top was accompanied by two dial measurements, mounted on the testing machine's moveable crosshead, and sharply focused. Utilized are dial measures with a 0.02mm minimum check. A General testing machine with 1000 KN limit is utilised as an example. The previous agents suggest a crosshead development rate of 0.02 mm per second for a respectable strain accounting.Examples are tested while under tension control and single pivot pressureaccording to May be: 516-1999 to get the pressure strain attributes. In the wake of acquiring the pressure strain conduct of traditional and bacterial cement tentatively, experimental conditions are created to speak to uni-hub stressstrain conduct of ordinary and bacterial cement blends. From those exact conditions, hypothetical worries for customary and cement bacterial are determined and contrasted and test esteems.

Examine flexuralconcrete

The examination were conducted to think about cement's flexural behaviour. A reasonable segment of 16 generally supported bars is tossed and tested. The pillar example's cross-segment measures 100 mm by 150 mm by 1200 mm. The pillars are thrown using normal evaluation concrete and standard grade concrete, both of which include and do not contain microorganisms.

SPECIMEN ARRANGEMENT

Specimen moulds are prepared by putting two wooden boards next to one another so that the distance between them is equal to the width of the thrown pillar. To take care of dividing, wooden pc of the necessary width are kept in the centre of the boards. The whole throwing process takes place on a level stage. The moulds cannot accommodate a base plate. To keep the edge in place, the mould closures have screws and nuts.

5. RESULT

The properties of materials which utilized to creating customary,cement bacterial concrete were appeared in Tables 1 and 2

Ordinary Portland Cement Property

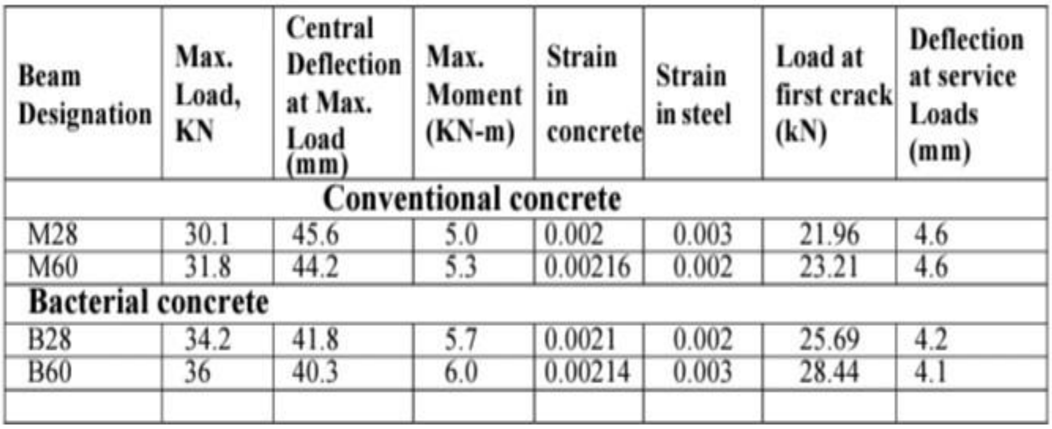
S.no.	CHARACTERISTICS	RESULTS	REQUIREMENTS AS PER IS code :12269-1987
1	SOUNDNESS-BY-LE-CHATELIER	1.5 mm	NOT MORE THAN 10 mm
2	FINENESS OF CEMENT	2 %	LESS THAN 10 %
3	FINAL SETTING TIME	240 minutes	NOT LESS THAN 600 MINUTES
	INITIAL SETTING TIME	55 minutes	NOT MORE THAN 30 MINUTES
4	SPECIFIC GRAVITY	3	NIL
5	NORMAL CONSISTENCY	31 %	NIL

AGGREGATESCHARACTERISTICS

Sieve Analysis: Fine aggregate

S.no	IS.code Sieve size	Wt. RETAINED (gm).	CUMULATIVE WT. RETAINED (gm)	CUMULATIVE PERCENTWt. RETAINED	Cumulative % PASS	GRADING LIMITS IS.CODE 383-1970 ZONE 2
1	10 mm	0	0	0	99.4	99.4
2	4.75mm	6.2	6.2	0.7	99.7	91-100
3	2.36mm	46	52	5.3	94.8	76-100
4	1.18mm	191	240	24.2	75.8	55-91
5	600microns	359	599	59.9	38.9	34-58

TEST RESULTOF BEAM



Beam Designation	Max. Load, KN	Central Deflection at Max. Load (mm)	Max. Moment (KN-m)	Strain in concrete	Strain in steel	Load at first crack (kN)	Deflection at service Loads (mm)
Conventional concrete							
M28	30.1	45.6	5.0	0.002	0.003	21.96	4.6
M60	31.8	44.2	5.3	0.00216	0.002	23.21	4.6
Bacterial concrete							
B28	34.2	41.8	5.7	0.0021	0.002	25.69	4.2
B60	36	40.3	6.0	0.00214	0.003	28.44	4.1

6. CONCLUSION

The following conclusions were taken from the in-depth tests conducted on the performance of standard grade ordinary and cement bacterial.

Bacteria Culture

Bacillus Subtilis is a bacteria found in soil.

In the lab, where it is safe and profitable, Bacillus subtilis can be supplied.

Training in Strength

Cement Mortar Cube's Compressive Strength

Testing for Split Tensile Strength and Compressive Strength in Concrete

- In conventional evaluation concrete, the expansion of Bacillus Subtilis microorganisms at 28 days increases the compressive quality by 13.93% compared to conventional cement.
- In conventionally evaluated concrete, as cement setting time moves from 18.65%, to 13.93% the amount of progress in compressive quality increases with the growth of microorganisms.
- In comparison to conventional cement, Bacillus subtilis microbe expansion at 28 days increases the compressive quality of standard grade concrete by 14.93%.
- In concrete of normal grade, as microorganisms multiply, the compressive quality advances to varying degrees as the solid's age changes.
- In comparison to regular cement, the expansion of Bacillus Subtilis bacteria at 28 days increases the split elasticity of typical evaluation concrete by up to 12.60%.
- In typical evaluation concrete, the level of advancement in the split elasticity is requested for 14.62% to 12.6% at various ages with the development of microorganisms.
- When compared to regular cement, the expansion of Bacillus Subtilis microscopic organisms increases the split elasticity of normal grade concrete up to 12.09 percent at 28 days.
- With the growth of tiny organisms in standard-grade concrete, the break rigidity enhancement level varies as cement ageing varies.

7. REFERENCES

[1] J. Wang, J. Dewanckele, V. Cnudde, S. Van Vlierberghe, W. Verstraete, and N. De Belie (2014). Proof of bacterial-based self-remedial in concrete using X-ray computed tomography. 289-304 in Cement and Concrete Composites.

[2] Rajor, A., Corinaldesi, V., Singh, K., and M. Singh (2016). properties of rice husk ash concrete made with microorganisms. 112-119. Construction and Building Materials, 121.

[3] N. Chahal, R. Siddique, & A. Rajor (2012). bacteria's effects on fly ash concrete's compressive strength, water absorption, and fast chloride permeability. 28(1), 351-356, Construction & Building Materials.

[4] Majid, M. Z. A., Andalib, R., and Hussin, M. W. (2016). Bacillus megaterium at its ideal concentration for fortifying structural concrete. 180–193 in Construction and Building Materials, 118.

[5] H. K. Kim, S. J. Park, J. I. Han, and H. K. Lee (2013). Calcium carbonate precipitation mediated by microbes on normal and lightweight concrete. 1073-1082 in Construction and Building Materials.

[6] Vijay, K., Murmu, M., and S. V. Deo (2017). A review of bacteria-based self-remedial concrete. 1008-1014 in Construction and Building Materials..

[7] K. Van Tittelboom, N. De Belie, W. De Muynck, and W. Verstraete (2010). The use of bacteria to repair concrete cracks. 157-166 in Cement and Concrete Research, 40(1).

[8] H. M. Jonkers, A. Thijssen, G. Muyzer, O. Copuroglu, and E. Schlangen (2010). Bacteria as a self-remedial agent in the development of sustainable concrete. 230-235 in Ecological Engineering.

[9] W. De Muynck, N. De Belie, and W. Verstraete (2010). A review of microbial carbonate precipitation in building materials. 118-136 in Ecological Engineering, 36(2).

[10] Williams, A. E., Warmington, J. R., and Bang, S. S., together with Bachmeier, K. L. (2002). Urease activity in the precipitation of calcite brought on by microbes. 93(2), 171–181 in Journal of Biotechnology.

[11] W. De Muynck, K. Cox, N. De Belie, & W. Verstraete (2008). An alternative concrete surface treatment is bacterial carbonate precipitation. Building and Construction Materials, 22(5), 875-885.

[12] .M. Jonkers, A. Thijssen, Bacteria mediated remediation of concrete structures, in Proceedings of the Second International Symposium On Service Life Design for Infrastructures (Delft, The Netherlands, 2010)