JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Experimental Investigation on Reinforcement Corrosion in Bacterial Concrete Using Impressed Current Technique Method

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Abstract : Reinforced concrete structures form a major part of the engineering infrastructure of all developed countries, and their integrity over long periods of service is of vital economic importance. But the major drawback is its low tensile strength which causes cracking in concrete. When micro cracks growth reaches the reinforcement, not only the concrete gets damaged, but also corrosion occurs in the reinforcement due to exposure to water and oxygen, and possibly CO2 and chlorides too. Micro-cracks are therefore the main cause for structural failure. There are a range of crack repair procedures available, but traditional restoration solutions have a number of drawbacks, including a different thermal expansion coefficient than concrete and negative impact on the environment and health. As a result, bio-based calcite precipitation has been presented as a viable and environmentally acceptable fissure healing method.Bio-mineralization of calcium carbonate is one such strategy to remediate cracks in building materials. Because oxygen is responsible for initiating the corrosion process, the consumption of oxygen during metabolic biochemical processes to generate CaCO3 is predicted to aid in the arrest of corrosion of steel, therefore enhancing the durability of steel reinforced concrete structures.In this thesis, an attempt has been made in the first phase to find the optimum concentration of bacterial cells to be incorporated in concrete. Based on the state-of-the-art information available in the literature three different bacterial samples are considered in concentrations of 104,105 and 106 cells/ml. The bacteria considered are Bacillus subtilis,Pseudomonas aerugonisa and Bacillus megaterium and the optimum concentration is found to be 105, 105 and 104cells/ml respectively based on compressive strength results.

Keywords*:* bio based calcite precipitation ,Bio-mineralization of calcium carbonate, CaCO3, Bacillus subtilis, Pseudomonas aerugonisa and Bacillus megaterium and the optimum concentration.

1 INTRODUCTION

The history of civil engineering and the use of cementing materials goes back as far as Egyptian times. The ancient Egyptians used calcined impure gypsum. The Greeks and Romans utilized calcined limestone, and subsequently learned to add sand and crushed stone, or brick and broken tiles to lime and water. This was the world's first concrete. Isaac Johnson invented modern cement in 1845, when he burned a combination of clay and chalk until it clinked, allowing the reactions essential for the production of powerfully cementitious compounds to occur.Concrete is one of the most versatile and widely used construction materials of all in the world. The proportionate mixture of cementing materials, water and aggregates, and sometimes admixtures, when placed in forms and allowed to cure, hardens into a rock-like mass known as concrete. The chemical interaction between water and cement causes the hardening. The voids of bigger particles (coarse aggregate) are filled by smaller particles (fine aggregate), and the voids of fine aggregates are filled with cement in this hardened concrete. The idea of considering concrete as a whole rather than its constituents as a construction material is gaining traction.The interest is now in having the desired properties of concrete without bothering about the ingredients.Concrete has high compressive strength, but its tensile strength is very low and hence cracks easily. In situations where tensile stresses are developed, the concrete is strengthened by steel bars forming a composite construction called Reinforced cement concrete (RCC). Reinforced concrete buildings are an important element of all industrialized countries' engineering infrastructure, and their long-term durability is critical to their economic viability.

1.1.Cracks - A Pathway for Corrosion Acceleration

Though concrete is quite strong mechanically, it is highly susceptible to larger tensile stress, and thus concrete structures get damaged and even fail unless some measures are adopted to counteract deterioration of concrete and thereby increasing the durability of concrete structure. A durable concrete is dense, workable having permeability as low as possible under the given situation. In the case of reinforced concrete, the ingress of moisture or oxygen through the cracks may lead to corrosion of steel, and cracking and spalling of concrete cover. Micro-cracks are therefore the main cause for structural failure. Any factor which may help in the development of cracks in concrete will promote the penetration of aggressive solution and gases, and will lead to the faster deterioration of concrete structure. Strength of reinforced concrete structures deteriorate with age also. Most common cause of construction deterioration is the corrosion of embedded steel reinforcement. Corrosion is supposed to affect the long term performance of structures. During the long term in corrosive conditions, the mass loss of the embedded steel rebars steadily increases. As a result there is a significant increase in the applied stresses on account of reduction of cross section of embedded steel and longitudinal cracks are induced in concrete reducing the bond between steel and the surrounding concrete. This may adversely affect the performance of existing structures.

1.2.Crack Repair Systems

All the concrete structures crack in some form or the other. An engineer should have a sound knowledge of all the facets of concrete technology. The problem of cracking should be tackled on two fronts, i.e., by adopting preventive measures and repairing them. However, prevention is better than repair. The designer and builders should attempt to reduce the formation of cracks by using appropriate construction materials, and by adopting appropriate design and construction techniques. Crack repairs can particularly be time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height. For crack repair, a variety of techniques is available but traditional repair systems have a number of disadvantageous aspects such as different thermal expansion coefficient compared to concrete and also have impact on environment and health. Therefore, bio based calcite precipitation has been proposed as an alternative and sustainable environmental friendly crack repair technique.

1.3.Advantages Of Bacterial Concrete

Calcium carbonate is one of the most naturally precipitated minerals on earth in the form of natural rocks and exists in environments such as marine water, fresh water, and soils. The evidence of microorganism involvement in calcium carbonate precipitation has lead to the use of these organisms in construction industry. The precipitation of calcium carbonate in concrete is expected to increase the strength of the structure. It is important to realise that micro organisms plug the pores of concrete not only due to its smaller size but also precipitates calcium carbonate when the micro organisms come into contact with air and moisture through the cracks. This precipitated calcium carbonate helps in filling the crack thereby reducing the probability of further propagation of cracks. The consumption of oxygen during the metabolic biochemical reactions to form $CaCO_3$ helps in arresting corrosion of steel because the oxygen is responsible to initiate the process of corrosion.

2.METHODOLOGY

1.To collect the literature review of this project.
2.Testing the various material properties like bacterial culture.
3.To casting of cubes for control specimen and with bacterial samples.
4. Study on mechanical characteristics of concrete (Compressive Strength).
5. To determination of optimal cell concentration.
6. To Casting of RC specimens for corrosion test.
7.To using Impressed current technique (Corrosion Acceleration).
8.To study of corrosion resistance property.
9. Comparsion of Results.
10.Conclusion.

2.1.Impressed Current Technique

The impressed current technique, also called the galvanostatic method, consists of applying a constant current from a DC source to the steel embedded in concrete to induce significant corrosion in a short period of time. After applying the current for a given duration, the degree of induced corrosion can be determined theoretically using Faraday's law, or the percentage of actual amount of steel lost in corrosion can be calculated with the help of a gravimetric test conducted on the extracted bars after subjecting them to accelerated corrosion. Using the actual amount of steel lost in corrosion, an equivalent corrosion current density can be determined. In this section, the circuitries used in the impressed current technique, the calculation of degree of induced corrosion and equivalent corrosion current density, and the relationship between theoretical and actual corrosion mass loss, are presented. Set-ups used for inducing reinforcement corrosion through impressed current consist of a DC power source, a counter electrode, and an electrolyte. The positive terminal of the DC power source is connected to the steel bars (anode) and the negative terminal is connected to the counter electrode (cathode). The current is impressed from counter electrode to the rebars through concrete with the help of the electrolyte (normally sodium chloride solution).

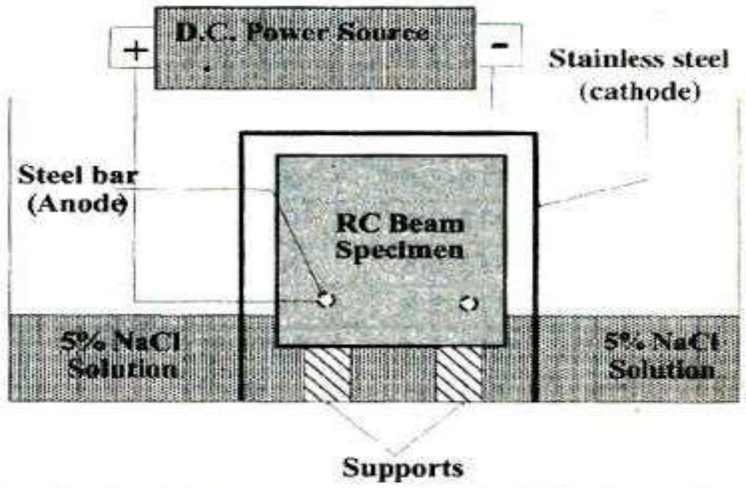

Figure 1:Impressed Current Technique

3.MATERIALS USED

Concrete is a composite material composed of cement (most commonly Portland cement), fine aggregate (sand), coarse aggregate (gravel or crushed stone), and sometimes chemical admixtures. Water reacts with (hydrates) the cement around the aggregate to form a solid, bonded conglomerate.

3.1.Cement

Cement is a finely ground mixture of calcium silicates and aluminates which set to a hard mass when treated with water. It is an inert material that exhibit characteristic property of setting and hardening when mixed to a paste with water. Construction process often requires a cement type based on the required performance of the concrete or the placement conditions for the production of mortar and concrete. The reason cement is one of the most common construction ingredients among other is its ability to hold the structure together. The most common type of modern cement is portland cement (sometimes referred to as OPC for "Ordinary Portland Cement"). This type of cement is typically made by grinding small rock-like bits of sintered limestone and alumino silicate minerals into a very fine powder. Its fast drying times combined with its higher compression strength compared to other cement, makes it a great choice for use in concrete, mortar, grout, and stucco. For all the tests, the samples of the cement shall be taken in accordance with the requirements of IS : 3535-1986.

3.2.Fine Aggregate

Aggregates are essentially granular materials used as ingredients to make up the proportion of concrete. Fine aggregates/ sand is an accumulation of grains of mineral matter derived from the disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles, but is distinct from clays which contain organic materials. Usually commercial sand is available from the river beds or from sand dunes originally formed by the action of winds. Much of the earth's surface is sandy, and these sands are usually quartz and other siliceous materials. The most useful commercially are silica sands, often above 98% pure. Fine aggregates must be passing through 4.75 mm sieve. Fine aggregate obtained from local river bed, clear from all sorts of organic impurities was used in this experimental program.

3.3.Coarse Aggregate

Coarse aggregate are the crushed stone used for making concrete. The commercial stone is quarried, crushed, and graded. Much of the crushed stone is granite, limestone, and trap rock. Graded crushed stone usually consists of only one kind of rock and is bro ken with sharp edges. The grading of coarse aggregate is important to get cohesive & dense concrete. The voids left by larger coarse aggregate particles are filled by smaller coarse aggregate particles and so on. Coarse aggregates can have round, angular, or irregular shape. Flaky and elongated coarse aggregate particles not only increase the water demand but also increase the tendency of segregation. Flakiness and elongation also reduce the flexural strength of concrete. Hence angular aggregates are most preferred. Angular aggregates of size 20 mm and below available from the local quarry is used as coarse aggregate.

3.4.Water

Water fit for drinking is generally considered fit for making concrete. Water should be free from acids, alkalies, oils or other organic impurities. Water has two functions in a concrete mix. Firstly, it reacts chemic ally with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a lubricant in the mixture of fine aggregates and cement. Water is also needed for the hydration of the cementing materials to set and harden during the period of curing. The quantity of water in the mix plays a vital role in the strength of concrete. Potable water was used in the experimental work for both mixing and curing purposes conforming to IS:456-2000.

3.5.Bacteria

Currently unease enzyme activity in most of microorganism metabolism process has been used as a tool to induce the precipitation of calcite crystals. Bacteria added to concrete mix in suspension state must meet certain criteria. Concrete is a highly alkaline building material, so bacteria used must be able to survive in this high alkaline environment for long durations and be able to form spores (highly resistant structures) withstanding mechanical forces during concrete mixing. Gram positive bacteria have extremely thick outer cell membrane that enables them to remain viable until a suitable environment is available to grow. They would become lively when the cracks form on concrete surface allowing water to ingress into the structure. This phenomenon will reduce the pH of the concrete environment where the bacteria incorporated become activated. A peptone based nutrients supplied along with bacteria in suspension helps in producing calcite crystals. It is found that this biomineralisation process will not interfere with the setting time of the concrete.

3.6.Microbial Precipitation Of Caco3

Bacterial cell walls, which comprise the cell surface, are known to be central to Microbially Induced Calcite Precipitation. Bacterial cell walls are negatively charged under environment of neutral or alkaline pH, attract the calcium ions (Ca2+) in the extracellular environment to react with the carbonate ions (CO32-) and form calcium carbonate (CaCO3) minerals on the cell surface, which serve as nucleation site for further mineralization. In medium, it is possible that individual microorganisms produce ammonia as a result of enzymatic urea hydrolysis to create an alkaline micro-environment around the cell. The high pH of these localized areas, without a significant increase in pH in the entire medium at the beginning, apparently commences the growth of CaCO3 crystals around the cell. Possible biochemical reactions to precipitate CaCO3 at the cell surface can be summarized as follows.

$Ca2^{+} + Cell \rightarrow Cell\text{-}Ca^{2+}$ ——————————— **Eqn 4.1**

$Cell\text{-}Ca^{2}{+} + CO3^{2}\text{-} \rightarrow Cell\text{-}CaCO3\downarrow$________ **Eqn 4.2**

3.7.Bacterial Culture

Culture of bacteria in the required concentration was obtained from Bharathiyar University, Coimbatore and the stock was preserved under refrigeration until further use. The cultures of Bacillus subtilis, Bacillus megaterium andS Pseudomonas aeruginosa were used in concentrations of 104, 105 and 106 cells/ml.

4.MATERIALS TESTS

Tables 1, 2, 3, and 4 indicate the findings of testing on fly ash, M-sand, coarse aggregate, and water, respectively, in this research. Manufacturing sand and river sand characteristics were also discussed.

Table 1:Tests on cements

Test Particulars	Results Obtained	Requirements As Per IS 12296-1970
Specific gravity	3.2	3.10-3.15
Normal Consistency	27%	30-35
Initial Setting Time	35 Minutes	30 Minutes
Final Setting Time	10 hours	10 hours

Table 2:Tests on Fine Aggregate

Test Particulars	Results Obtained	Requirements As Per IS 12296-1970
Specific Gravity	2.67	2.6-2.9
Bulk Density	1481.48kg/m^3	1200-1750kg/m^3
Grading of F.A	100	Zone II

Table 3:Tests on Coarse Aggregate

Test Particulars	Results Obtained	Requirements As Per IS 12296-1970
Specific Gravity	2.875	2-3
Bulk Density	1762.96kg/m3	1200-1750kg/m^3
Fineness Modulus	5.13	3.5 to 6.5

5. CONCRETE MIX DESIGN

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing.

5.1.Factors to be considered for Mix Design

1.The grade designation giving the characteristic strength requirement of concrete.
2.The type of cement influences the rate of development of compressive strength of concrete.
3. Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
4. The cement content is to be limited from shrinkage, cracking and creep.
5. The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

Table 4:Mix Proportion

Grade	Cement	Fine Aggregate	Coarse Aggregate	Water
M20	413.33kg/m^3	607.23kg/m^3	1203.86kg/m^3	186litres
	1:1.469:2.913:0.45			

6.EXPERIMENTAL METHODOLOGY

This chapter presents the experimental study carried out to determine the compressive strength and water absorption of concrete cubes. It also discusses the corrosion of reinforced concrete and the procedure for accelerating corrosion in the R.C.C. beams.

6.1.Compressive Strength Of Concrete

Compressive Strength of concrete is an important element in designing R.C.C. structures. It is given in terms of the characteristic compressive strength (fck) of 150 mm size cubes tested at 28 days.

6.2.Preparation of Test Specimens

Initially the cube moulds are fixed and oiled before pouring concrete into it. The mould shall be of 150 mm size conforming to IS:10086-1982. The materials shall be mixed properly in proper proportions arrived from mix design and the concrete shall be fil led into the mould in layers approximately 5cm deep. Each layer shall be compacted either by hand subjected to 35 strokes per layer or by vibration. De-moulding shall be done after 24 hours with utmost care to prevent any damage to the specimen and must be ensured that concrete has attained hardened state before demoulding. The specimen shall be stored in water at a temperature of 27°± 2°C until the time of test.

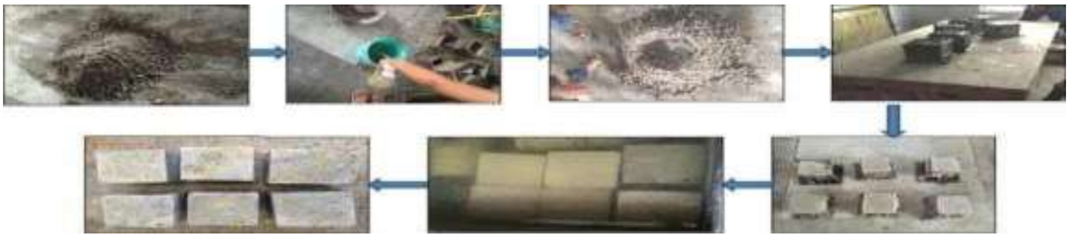

Figure 2:Preparation of Test Specimens

6.3.Testing Procedure

Tests shall be made at recognized ages of the test specimens, the most usual being 7and 28 days. The specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq.cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen shall then be recorded. In this thesis, the cubes were cast for the control mix and for three concentrations of three bacterial specimens, 10^4, 10^5, 10^6 cells/ml of mixing water for Bacillus subtilis, Bacillus megaterium and Pseudomonas aeruginosa. The cubes were tested at the ages of 7 and 28 days. The total numbers of cubes cast were 60.

Figure 3:Testing Procedure

The measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by the cross sectional area.

7.RESULTS AND DISCUSSION

7.1.Cube Compressive Strength

The compressive strength test was carried out on cubes cast for the concentrations (104,105,106 cells/ml) of all bacteria considered (Bacillus subtilis, Bacillus megaterium, Pseudomonas aeruginosa). The test was done at the age of 7 and 28 days and the results are shown in the following tables 6.1,6.2,6.3,6.4. The optimum cell concentration of each bacterium was found based on these results.

Table 5: Compressive Strength Results of Control Concrete

S.No	Compressive Strength(N/mm^2)	
	7 days	28 days
1	20.00	30.27
2	22.22	30.06
3	21.33	30.95
Average	**21.18**	30.43

Table 6: Compressive Strength Results of Bacillus Megaterium

S.No	Compressive Strength (N/mm^2)					
	10^4 cells/ml		10^5 cells/ml		10^6 cells/ml	
	7 days	28 days	7 days	28 days	7 days	28 days
1	24.63	45.95	22.33	33.15	21.01	32.79
2	29.89	46.37	24.52	36.23	20.04	32.44
3	28.06	47.45	23.28	37.46	19.01	30.22
Average	**27.53**	**46.59**	**23.38**	**36.61**	**20.02**	**31.82**

Table 7: Compressive Strength Results of Bacillus Subtilis

S.No	Compressive Strength (N/mm^2)					
	10^4 cells/ml		10^5 cells/ml		10^6 cells/ml	
	7 days	28 days	7 days	28 days	7 days	28 days
1	22.36	35.36	33.87	46.59	24.89	34.67
2	21.57	32.21	36.62	41.15	29.04	37.78
3	24.12	36.56	33.52	42.65	23.15	35.56
Average	22.68	34.71	34.67	43.46	25.69	36.00

Table 8: Compressive Strength Results of Pseudomonas aeruginosa

S.No	Compressive Strength (N/mm^2)					
	10^4 cells/ml		10^5 cells/ml		10^6 cells/ml	
	7 days	28 days	7 days	28 days	7 days	28 days
1	24.72	44.39	29.42	45.04	21.18	34.60
2	27.64	45.70	32.09	46.87	23.36	33.84
3	23.02	40.80	30.92	45.45	22.22	32.26
Average	25.13	43.63	30.81	45.79	22.49	33.57

It was observed that the compressive strength of the cubes with bacteria was higher than those cast without bacteria. It can be seen that the maximum compressive strength was obtained for 105cells/ml for Bacillus subtilis and Pseudomonas aerugonisa and 104cells/ml for Bacillus megaterium.The optimum concentrations of the bacterial specimens showed an increase in compressive strength at 7 and 28 days when compared with control specimens.

Table 9: Effect of bacteria addition on compressive strength of concrete

Specimen Type	Average 28 Days Compressive Strength,Mpa	%Increase In Strength
Control Specimen	30.43	-
Bacillus Subtilis(10^5 Ells/ml)C	43.46	42.8
Pseudomonas Aerugonisa(10^5 Ells/ml)C	45.79	50.5
Bacillus Megaterium(10^4 Ells/ml)C	46.59	53.5

It was observed that there was a maximum of 53.5 % increase in compressive strength for the cubes cast with 104 cells/ml concentration of Bacillus megaterium.The optimum concentrations of other considered bacteria also showed a significant increase in compressive strength.

8.CONCLUSION

The influence of varying the impressed current level to accelerate steel reinforcing corrosion in concrete structures was experimentally investigated. The study evaluated the concrete crack pattern, time vs. crack, and the mass loss due to accelerated corrosion upto development of first visible surface crack on concrete specimen.The level of voltage applied had no effect on the final crack pattern. For all test specimens, the cracks due to corrosion of reinforcement were parallel to the steel reinforcing bars regardless of the level of voltage applied to induce the corrosion of reinforcement. Time required for the development of first visible crack on the surface of concrete increases with the increase in C/D ratio for same voltage applied (4V, 6V, 10V). The time required for development of first visible crack on concrete surface decreases with increase in voltage (4V, 6V, 10V) for same C/D ratio. Mass loss decreases with increase in C/D ratio for same voltage applied upto development of first visible surface crack on concrete specimen. Mass loss decreases with increase in voltage for same C/D ratio upto the development of first visible surface crack on concrete specimen More research work is required to investigate the ability of corrosion of reinforced concrete at higher voltage and at higher degrees of corrosion

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IS CODES

[1] IS 383:1970, Specification for coarse and fine aggregates from natural sources for concrete.
[2] IS 456:2000, Plain and Reinforced concrete-code of practice.
[3] IS 516: 1959, Methods of tests for Strength of concrete.
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ASTM STANDARDS

[1] ASTM C 642-97, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete.
[2] ASTM G 1-90, Standard Practice for Preparing, Cleaning, and Evaluation Corrosin Test Specimens.