International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume – 02, Issue – 03, March – 2017, PP – 84-97

IMPROVEMENT OF CONCRETE DURABILITY BY BACTERIAL MINERAL PRECIPITATION

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Abstract: This project work mainly deals with the study of improving the durability of concrete by bacterial actions. The durability of concrete is mainly lost due to chemical and environmental factors. So let's discuss about durability and different type of durability attacks on concrete.

Introduction:

A durable material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement. Construction and demolition waste contribute to solid waste going to landfills. The production of new building materials depletes natural resources and can produce air and water pollution. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years or longer. soluble substances which are easily eroded, thus producing concrete disintegration. Many acids are used directly in industrial processes. In other industries, acids develop as a result of bacterial growth in waste or spilled material.

1.1 Durability

Durability is the ability to last a long time without significant deterioration. A durable material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement. Construction and demolition waste contribute to solid waste going to landfills. The production of new building materials depletes natural resources and can produce air and water pollution. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years or longer. Most concrete and masonry buildings are demolished due to obsolescence rather than deterioration. A concrete shell can be left in place if a building use or function changes or when a building interior is renovated. Concrete, as a structural material and as the building exterior skin, has the ability to withstand nature’s normal deteriorating mechanisms as well as natural disasters. Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than an indoor concrete floor

1.2 Attacks on Concrete

Fig 1.1 Attacks on concrete

As shown in Fig 1.1, concrete structures are subjected to various attacks that generally damage the material present in it, so entire structure gets deteriorated. These attacks are generally of two types physical disintegration and chemical disintegration. Physical attacks are generally not prevalent in all areas, they are generally prevalent only in extreme climatic conditions and may occur due to physical deterioration..

ACIDS

Acids combine with calcium compounds in hydrated cement to form soluble substances which are easily eroded, thus producing concrete disintegration. Many acids are used directly in industrial processes. If their presence is anticipated, they can be handled properly to avoid attack on the concrete. Concrete can be destroyed by prolonged contact with strong solutions of sulfuric, sulfurous, hydrochloric, nitric, hydrobromic and hydrofluoric acids. These same acids in solutions of less than 1 percent concentration will attack more slowly but still significantly. Acids with low pH values are destructive

BASES

Bases are chemical compounds such as ammonia water and caustic soda which yield hydroxyl ions (OH^-) in water solutions, they neutralize acids into salts and have pH values above 7.0. When portland cement concrete is made with non-alkaline active aggregates, it is highly resistant to strong solutions of most bases. Calcium, ammonium, barium and strontium hydroxides are normally harmless, but sodium hydroxide may cause damage.

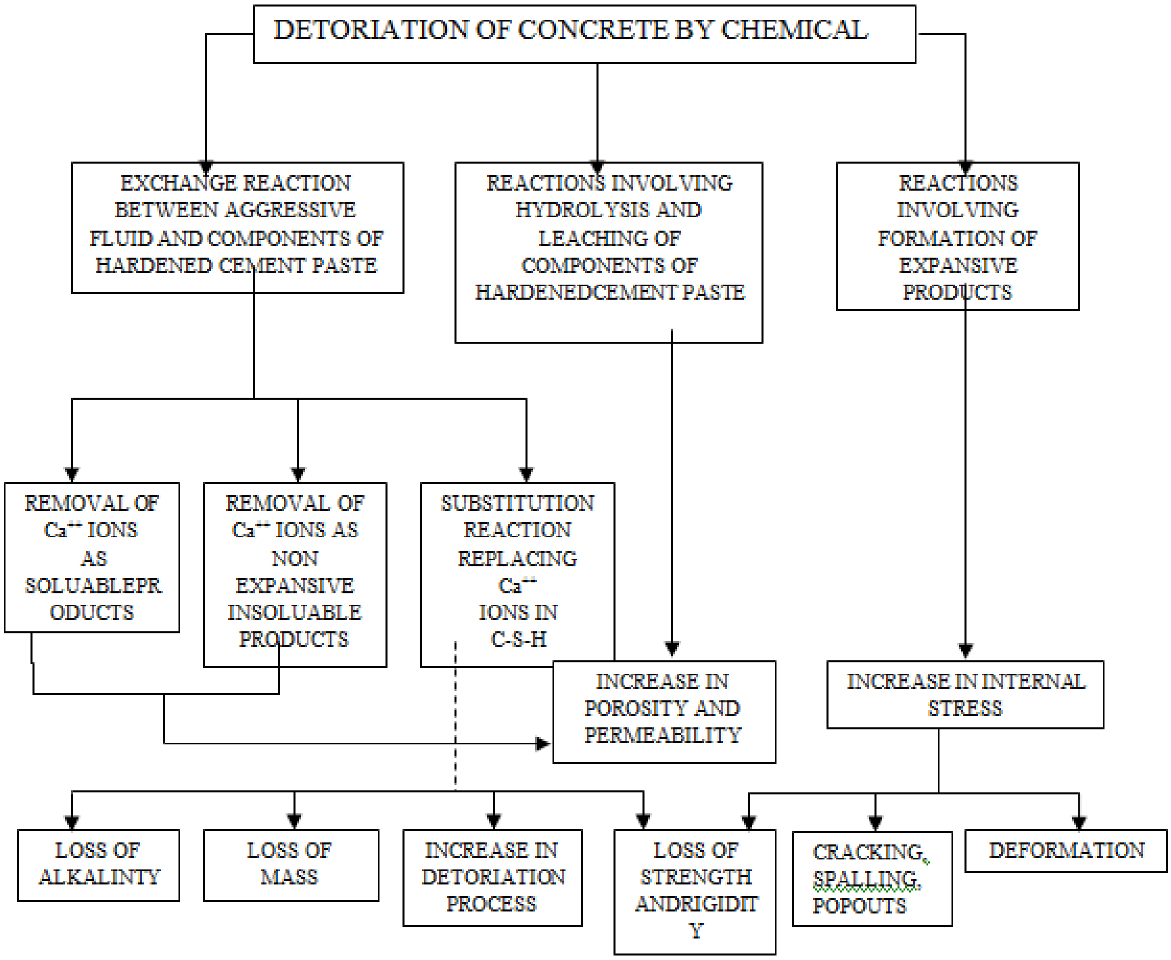
SALTS

Salts are chemical compounds usually formed by reaction between acids and bases. Ordinary table salt (sodium chloride) is a familiar example. Sodium chloride does not attack concrete chemically but contributes to the corrosion of reinforcing steel and when used as a deicer, participates in and aggravates physical damage resulting from freezing and thawing. The chlorides and nitrates of ammonium, magnesium, aluminum and iron all cause concrete deterioration, with those of ammonium producing the most damage.Some of the salts best known for their damaging effects on concrete are the sulfates

FREEZING AND THAWING

Deterioration of concrete from freeze thaw actions may occur when the concrete is critically saturated, which is when approximately 91% of its pores are filled with water. When water freezes to ice it occupies 9% more volume than that of water.freezing may cause distress in the concrete. Distress to critically saturated concrete from freezing and thawing will commence with the first freeze-thaw cycle and will continue throughout successive winter seasons resulting in repeated loss of concrete surface. To protect concrete from freeze/thaw damage, it should be air-entrained by adding a surface active agent to the concrete mixture

1.3 LOSSES ON CONCRETE



The above flow chart explains various deterioration of concrete by chemical attacks. There are three main ways by which the concrete gets deteriorated by the exchange reaction between aggressive fluid and components of hardened cement paste, hydrolysis and leaching of concrete components, formation of expansive products. The reaction of aggressive fluid and components of concrete generally involve the removal of calcium ions in three different ways i.e., Soluble products, Expansive insoluble products, and by C-S-H ions. Soluble products, Expansive insoluble products leads to loss of alkalinity, loss of mass, increase in deterioration process and also in losing the strength and rigidity of concrete but replacing in C-S-H ions leads only to the loss of strength and rigidity of concrete. Hydrolysis and leaching of components leads only to the increase in porosity and permeability. Formation of expensive products leads to increase in internal stresses which in turn leads to loss of strength and rigidity, cracking and spalling pop outs, and also leads to deformation.

1.4 NEED FOR THE STUDY

Concrete structures are prone to various destructions these days by various reasons, mainly due to chemical reactions that happens due to heavy pollutions today. Other common deterioration factors in concrete are natural calamities like freeze and thaw effects. Concrete though subjected to such various affects concrete itself could withstand these effects to a certain limit. It becomes very difficult only when these attacks penetrate into the concrete surface through cracks. So it is our prime duty to save our concrete from such destructions. There are many technology today to seal these cracks like grouting, plastering etc. But these technologies sometimes prove to be very hard to work with. Sealing with these technologies may seal the outer surface but these may not reach the inner surface of the cracks. Thus though the crack may been seen to be sealed completely but they are not sealed properly, this makes the concrete liable to further attacks.

Bacterial concrete can be used as a solution for this problem. The calcite which is precipitated by the MICCP process will seal the crack from the inner surface to the outer surface, hence the crack is completely sealed. And it is well known that calcite is also called as natural cement and is inert in nature. Therefore they can withstand any chemical attacks and these type of calcite filler forms a strong covalent bond between the two surface of the cracks , and thus the strength of the concrete also gets increased.

1.5 SCOPE AND OBJECTIVE

The major scope of our research work is to investigate the calcium carbonate precipitation by urease positive bacterium and their performance when subjected to chemical attacks. This will ensure the durability aspects imparted by the layer formed. Then this MICCP process is applied in crack remediation's on concrete surfaces and our work objectives are

- For analyzing durability of concrete test like acid, chloride, sulphate, carbonation attacks will be done.
- Weight loss on concrete will be analyzed to ensure the durability after chemical attack on concrete .
- Crack remediation techniques are proposed for remediating old structure and for newly constructing structure.
- SEM images will ensure the crystal formation on the concrete surface and the presence of bacterial spores in it.
- EDAX test will ensures the material that is been deposited by the bacterium.

1.6 SCHEME OF OUR PROJECT

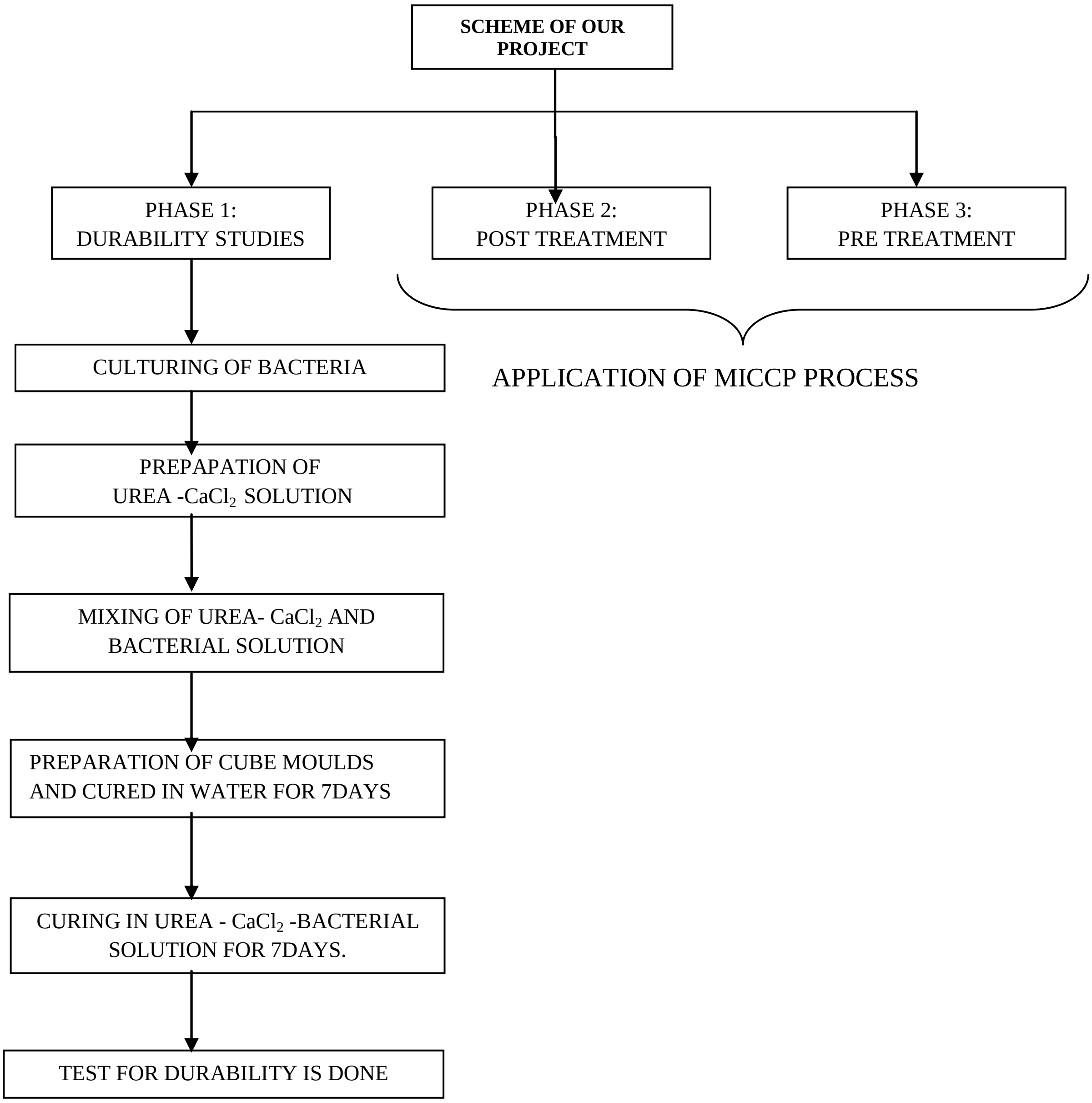


Fig 1.2 Scheme of our project

1.7 BACTERIAL PROCESSES

BACTERIAL STOCK COLLECTION

Urease positive bacteria like Bacillus Pasteurii(B.P), Bacillus Megaterium(B.M), Bacillus Sphaericus(B.S) have been chosen for our work. This bacterial stock cultures are purchased from "National Collection Of Industrial Microorganisms (NCIM) National Chemical Laboratory, Dr.HomiBhabha Road, Pune411008,Maharashtra, India."

Fig 1.3 Bacterial stock culture from NCIM

The Stock (fig 1.3)purchased is been maintained at Nutrient Agar medium i.e.

Agar	20.0g
NaCl	5.0g
Peptone	10.0g
Beef extract	10.0g
Distilled water	1.0 L
PH	Adjusted between 7 - 7.5

1.8 CULTURINGMETHODS OF BACTERIA

Nutrient broth is used for culturing these bacterium. Initially Bacterial colonies have been made by inoculating in petriplates as show in fig 1.4

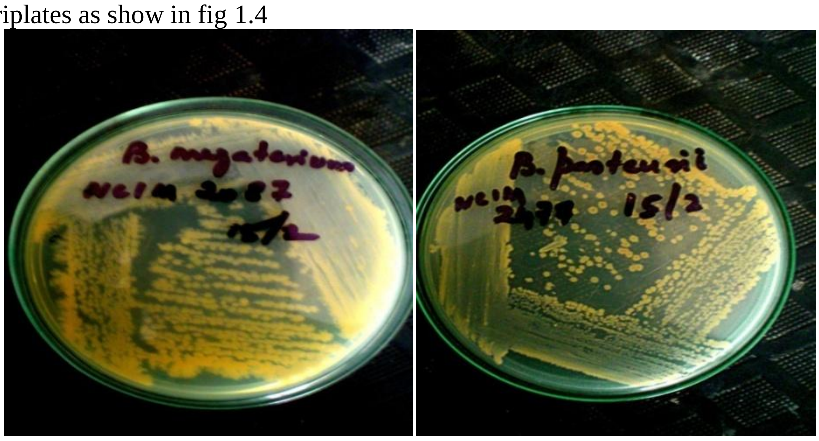


Fig 1.4 Bacterial growth in petriplates

Inoculate these colonies of bacteria in 50 ml Nutrient broth and incubate overnight in a shaker at room temperature to get actively growing cells. Prepare and autoclave nutrient broth, Inoculate the nutrient broth with the actively growing .

Fig 1.5 Bacteria in nutrient agar medium

cell at 10% level and incubate for 24h at room temperature. After 48hours nutrient broth contains active bacteria at a rate of 1 X 10^9 cells/ml (fig 3.4). Since 1 X 10^8 cells/ml itself is satisfactory, 5litres of bacterial solution can be mixed with 45litres of distilled water.

1.9 MICCP PROCESS

Microbiologically Induces Calcium Carbonate Precipitation(fig3.5) is a process in which the bacteria deposits calcite layer is over the concrete due to microbial or bacterial actions. Since it is used for remediating cracks and fissures in harden concrete it can be termed Microbiologically Enhanced Crack Remediation (MECR). These calcite formed by the bacteria can be known as biocement.

$(Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3\downarrow)$

$Ca^{2+} + Cell \rightarrow Cell\text{-}Ca^{2+}$ . . . . (1)

$Cl^{-} + HCO_3^{-} + NH_3 \rightarrow NH_4Cl + CO_3^{2-}$ . . . . (2)

$Cell\text{-}Ca^{2+} + CO_3^{2-} \rightarrow Cell\text{-}CaCO_3\downarrow$ . . . . (3)

2.0 PRELIMINARY STUDIES

Preliminary studies are done to all the materials that have been used in concrete. These test are done as per the recommendations of IS standards. After these test materials have been chosen into account for using in our project.

CEMENT

The cement used to cast cube moulds is Dalmiavajram cement of 53 grade cement. Initially fineness test, heat of hydration test are done.

FINE AGGREGATE

The fine aggregate from river bed is made available in our college campus itself. Initially fine aggregate was passing through 4.75 mm sieve to remove the coarse grained particles and to maintain grain size as 4.75 and below.

COARSE AGGREGATE

The coarse aggregate used were available in our college from local quarry. The size of aggregate used is 10mm – 20mm. The coarse aggregate was passing through 40mm sieve. While sieving care must be taken to avoid the entrainment of plastics, twigs, dried leaves etc. This may cause reduction in compressive strength.

SPECIFIC GRAVITY TEST

In concrete technology, specific gravity of materials is made use of in design calculation of concrete mixes. With the specific gravity of each constituent known, its weight can be converted into solid volume and hence a theoretical yield of concrete per unit volume can be calculated. Specific gravity of aggregate is also required in calculating the compacting factor in connection with the workability measurements. Specific gravity of cement, fine aggregate and coarse aggregate is done using pycnometer. Determine and record the weight of the empty clean and dry pycnometer, W_P. Place sample in the pycnometer. Determine and record the weight of the pycnometer containing the dry soil, W_{PS}. Add distilled water to fill about half to three-fourth of the pycnometer. Soak the sample for 10 minutes. Fill the pycnometer with distilled (water to the mark), clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and contents, W_B. Empty the pycnometer and clean it and fill it with distilled water to the mark. Clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and distilled water, W_A. Empty the pycnometer and clean it

By calculating specific gravities of cement, fine aggregate and coarse aggregate comes as 3.16, 2.6, 3.033 respectively

SIEVE ANALYSIS

This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call as gradation. A convenient system of expressing the gradation of aggregate is one which the consecutive sieve opening are constantly doubled, such as 10mm, 20mm, 40mm, etc. under such a system employing a log scale, lines can be spaced at equal intervals to represent the successive sizes.

The aggregate used for making concrete are normally of the maximum size 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 600microns, 300microns and 150 microns. The aggregate fractions from80mm to 4.75 are termed as coarse aggregate the size 4.75mm is a common fraction appearing both in coarse aggregate and fine aggregate. By comparing the test results with IS 383 – 1970 fine aggregate & coarse aggregate comes under zone II..

INITIAL SETTING TIME

Lower the needle gently and bring it in contact with the surface of the test block and quickly release. Allow it to penetrate into the test block, in the beginning the needle will completely pierce through the test block. But after some time when the paste starts losing its plasticity, the needle may penetrate only to a depth of 33-35 mm from the drop. The period elapsing between the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 33-35 mm from the top is taken as initial setting time. It is found from experiments that the initial setting time is 33min.

FINAL SETTING TIME

Replace the needle of the vicat apparatus by a circular attachment. The cement shall be considered as finally set when ,upon lowering the attachment, gently cover the surface of the test block, the centre needle makes an impression while the circular cutting edge of the attachment fails to do so. In other words the paste has attained such hardness that the center needle does not pierce through the paste more than 0.5mm. the final setting time is found as 10hrs.

2.1 CONCRETE CUBE MOULDS PREPARATION FOR ATTACKS

Initially M20 design of concrete were made with a water cement ratio 0.5 and six cube moulds of dimension 15 × 15 × 15 cm is casted. The cubes were de molded after a day. Now one cube is normally cured in water and rest two cubes were cured in bacterial solutions one in each type. For preparing bacterial solutions we took two separate tubs and filled with urea-$cacl_2$ solution of pH 7 to 7.2 then we suspended bacillus Sphaericus in one tub and bacillus Megaterium in another tub . Now the cubes were placed in these two tubs and were cured for 14 days .Now after the 14 days of curing all the three cubes were taken and a weight analysis were made. Then these concrete were washed gently and then were sundried.

Fig 2.1Mixing of concrete for preparing cube moulds

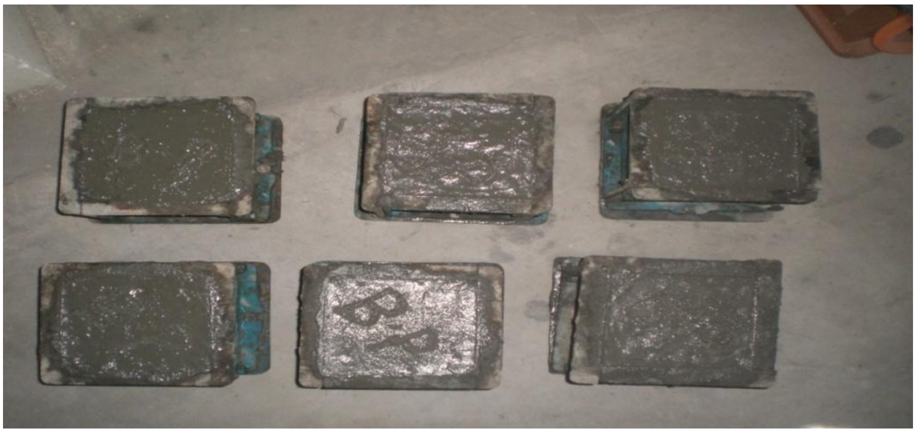


Fig 2.2Cube moulds were made and dried for one day

Fig 2.3Demolded specimens kept for curing

Fig 2.4Curing of specimens in water

Fig 2.5Curing of specimens in bacterial solution

Fig 2.6 Preparation of chemical solutions to check chemical attack

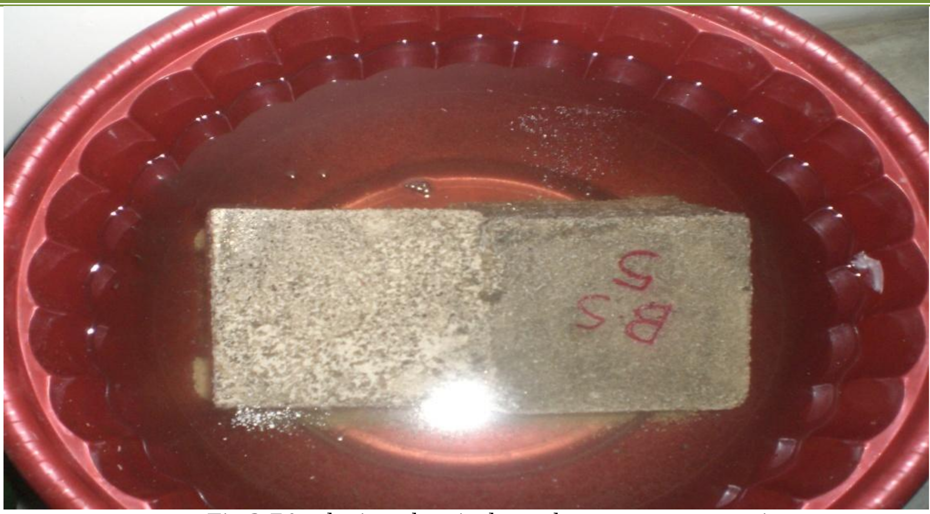


Fig 2.7Analyzing chemical attacks on concrete specimens

During bacterial curing period Nutrient agar is added for every two days. This is added because the bacteria may tend to spourlate during the curing process if nutrient agar content becomes less.

Fig2.8 Nutrient Agar powder for preparing Nutrient broth

Initially Nutrient agar powder is taken for preparing Nutrient broth for the bacteria to survive during the curing period of 7 days, this nutrient agar consist of constituents that is been mentioned in table

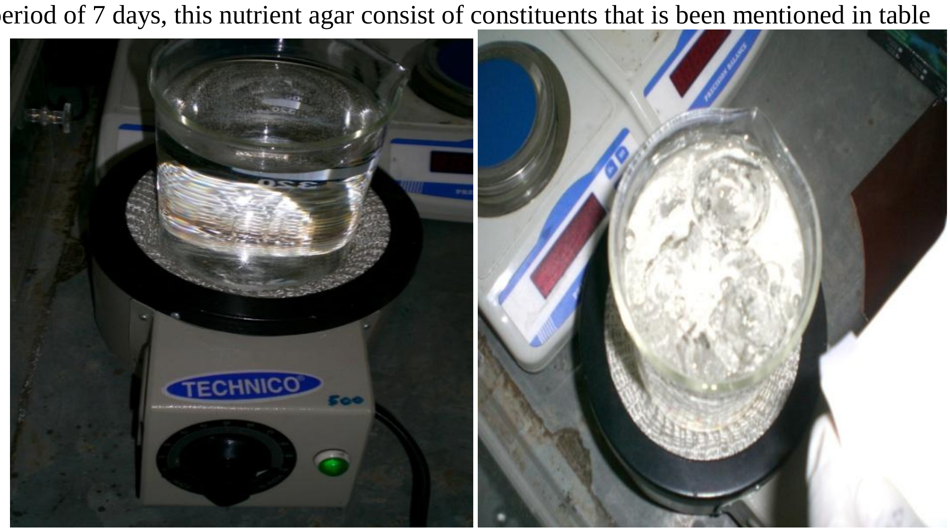


Fig2.9 Boiling of distilled water to prepare NB

One litre of disstilled water is taken in beaker and it is been boiled for 10minutes as shown in fig 3.14 . Then 10g of nutrient agar powder is measured and mixed with boiled distilled water by constant stirring. Care must be taken while adding nutrient agar in distilled water beacause it may form lumps.

Fig 2.10 Mixing of Nutrient Agar to prepare Nutrient Broth

After NA is mixed with distilled water, it has to be boiled for 15 minutes. Then Nutrient broth is cooled at room temperature and added to curing tubs.

Fig 2.11 Boiling of Nutrient broth

2.2 DURABILITY STUDIES

ACID ATTACK

Concrete Experts International has extensive, world-wide experience with deteriorated concrete suffering from acid attack caused by acid smoke, rain and exhausting gasses. Diagnosing acid attack is an integrated part of our petro graphic analysis of concrete. Concrete is susceptible to acid attack because of its alkaline nature. The components of the cement paste break down during contact with acids.Most pronounced is the dissolution of calcium hydroxide which occurs according to the following reaction:

$$2\ HX + Ca(OH)_2 \rightarrow CaX_2 + 2\ H_2O$$

(X is the negative ion of the acid)

PROCESS APPLIED TO STUDY ACID ATTACK.

Acidic solutions were prepared. To prepare 1N of sulphuric acid solution we took in the 27.222 ml of concentrated sulphuric acid(99.99% pure) in 1000ml of distilled water. Now the concrete were placed in it for five days. After that the concrete cubes were taken out , washed properly sun dried for some time, then again a weight analysis were made. Then all these cubes were compression tested to check their strength variations.

CHLORIDE ATTACK

Chloride attack poses a significant threat to reinforced concrete especially for structures in marine environments or those that are likely to be exposed to high concentrations of salts. The net result of chloride attack is the corrosion of steel reinforcement, leading to cracking and spalling of concrete and in some cases catastrophic structural failure as the load bearing capacity of the concrete is compromised. The mode of attack relies on salts and other corrosive substances, carried by moisture, being absorbed into the concrete via its pores and micro pores through capillary action. Once absorbed, these substances act to reduce the pH value of the concrete thereby eliminating its passive oxide layer which would otherwise provide protection to the steel reinforcement. Corrosion takes place as the chloride ions meet with the steel and the surrounding passive material to produce a chemical process which forms hydrochloric acid. The hydrochloric acid eats away at the steel reinforcement

2.3 FACTORS AFFECTING THE RATE OF CHLORIDE ATTACK

There are a number of factors that contribute to the rate at which concrete deterioration can occur as a result of chloride attack. The physical characteristics of the concrete itself are chief among these variables. By its very nature, concrete is a porous material with the degree of its strength and durability determined by factors such as the water/cement ratio, compaction and curing. Given the action of chloride attack, the density of concrete becomes an important influencing factor on the rate of its deterioration: concrete with smaller pores and lower pore connectivity will absorb less water or vapour and inhibit its transport thus slowing down the ingress of chlorides into the structure.

The physical condition of surface concrete plays an important role in the rate of deterioration. Where there is existing surface damage particularly in the form of abrasions, cavities or other impact damage the resultant cracks serve to speed up the transportation of moisture and ions to the steel which amplifies the rate of corrosion. Freeze thaw cycles can then exacerbate the process further.

2.4 CONCLUSION

Durability studies has been carried out and found that Bacillus Megaterium performs wells against chemical attacks. So we can say that the biocement or calcite formed by the bacillus Megaterium will have high resistance towards chemical attacks. In same way bacillus Sphaericus also deposited considerable calcite on concrete surface but the withstanding capacity of calcite formed is quiet less when compared to bacillus Megaterium. Coming on to the compressive strength part, Bacillus Sphaericus performs well in increasing the concrete compressive strength, though Bacillus Megaterium performs well in durability studies, It didn't give satisfyable results as bacillus Sphaericus. In the application part of this studies i.e., MICCP process, we analyzed using bacillus Pasteurii which is well known urease positive bacteria. The calcite production by bacterium in MICCP process was confirmed by SEM and EDAX images. SEM images clearly shows the calcite crystal structure formed on the surface of concrete. EDAX shows calcium as peak element present on the surface.

2.5 APPLICATION PART OF OUR STUDIES

- Our studies on durability can be applied for normal construction and it
  applied on the curing part of the structure. But drawback is the offence odor produced by the bacteria while curing.
- Prefabricated structures manufacturers can implement this type of curing techniques for improving the durability aspects of each and every member.
- Crack remediation's can also be applied for every structure, but the healing time depends on the crack type and its thickness.

2.6 FUTURE SCOPE

Thus in our project we had found that these urease positive bacteria will deposite calcium carbonate over the surface of concrete and these calcite layer has also found to protect the concrete to certain limit from the corrosive attacks. In future studies can be undertaken on the application part of this biomaterial. Research can be undertaken on the ways by which these bio mineral precipitation can be applied in the cracks remediation's on concrete, so studies can also be undertaken on how these phenomenon helps the concrete to attain good strength.

2.7 APPENDIX

SIEVE ANALYSIS FOR FINE AGGREGATE

The sieve analysis for fine aggregate was done and value are tabulated,

S.NO	IS Sieve mm	Cumulative % retained	Cumulative % finer (N)
1	2.36	5	95
2	1.7	12.2	87.8
3	1.2	29	71
4	0.6	54.8	45.2
5	0.425	84.2	15.8
6	0.3	97.4	2.6
7	0.15	99	1
8	0.075		0

SPECIFIC GRAVITY
Specific gravity is the ratio of the density of a substance compared to the density (mass of the same unit volume) of a reference substance

FINE AGGREGATE
Mass of Pycnometer (M1) = 650 g
Mass of Pyc. + sand (M2) = 910 g
Mass of Pyc. + sand + water (M3) = 1620 g
Mass of Pyc + water (M4) = 1460 g
Specific Gravity G $= \frac{M2-M1}{(M2-M1)-(M3-M4)}$
Specific Gravity Fine aggregate = 2.6

COARSE AGGREGATE
Specific gravity of coarse aggregate $= \frac{(W2-W1)}{\{(W2-W1)-(W3-W4)\}}$
W_1 = empty weight of pycnometer , W_1 = 0.70 kg
W_2 = weight of pycnometer + coarse aggregate , W_2 = 1.425 kg
W_3 = weight of pycnometer + coarse aggregate + water ,W_3 = 2.017 kg
W_4 = weight of pycnometer+ water , W_4 = 1.531 kg
Specific gravity of coarse aggregate = 3.033

CEMENT
Specific gravity = $\frac{(W2-W1)}{(W2-W1)+\{(W4-W3)\text{specific gravity of kerosene}\}}$
Weight of empty pycnometer , W_1 = 41g
Weight of bottle + Soil, W_2 = 50g
Weight of the bottle + Soil + Water,W_3 = 90.5g
Weight of the bottle + Water, W_4 = 83g
Specific gravity of kerosene = 0.82
Therefore Specific gravity of Cement = 3.16

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