

Experimental Study on Bio-Mineralization Process of Microbial-Cementation in Concrete Crack Remediation

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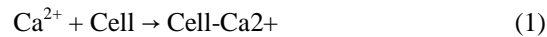
ABSTRACT: In this investigation, Concrete without cement is possible with the use of Microbial Induced Calcite Precipitate (MICP) as an alternate for cement. The green alternative to cement is use of Material+urease- producing microorganisms+urea+soluble calcium=Microbial-Cement, which has almost same chemical and physical property as cement. It improves its strength and durability of concrete. Microbial-cementation and Bio- clogging process occurs. The main failure in the structure is crack, which is unavoidable in concrete and make the concrete element weak. Water and other salts seep through these cracks, corrosion initiates, and thus reduce the life span of concrete, so there is a need to develop an inherent biomaterial for crack and regaining the strength of concrete structures. In this study, a biological self-repairing technique is highly desirable because the mineral precipitation induced as a result of microbial activities is pollution free and natural. Bio-Mineralization process Occurs, It will precipitate Calcium carbonate (caco3) through air medium or water medium which can remediate the cracks and fissures in concrete. The experiment were carried out using M40 mix of concrete to evaluate the effect of Sporosarcina pasteurii in microbial-concrete on the Compressive strength, Tensile strength for 7,14 and 28 days and compared with conventional concrete . MICP was quantified by EDXS (energy dispersive X-ray spectroscopy) analysis and visualized by Scanning Electron Microscopy (SEM).

KEYWORDS: Bio mineralization, MICP, Microbial cement, Bio clogging, Sporosarcina pasteurii, EDXS, SEM.

I. INTRODUCTION

Cement is the binding material, a substance that sets and hardens independently and can bind other materials together. In ancient civilization the binding materials were of traditional type such as jiggery, lead, jute, rice husk etc., now in modern civilization cement is main building materials [8]. Cement has excellent binding property but its production requires large amount of energy which contributes for pollution and global warming. The process of cement production starts from mining for raw materials, crushing, blending and heating these materials at high temperature at 1500^oc and finally creating cement from heated material. All the process involves in manufacturing of cement requires large amount of energy, It involves huge cost, Contributes to increase in co2 emissions and other greenhouse gases. As the demand for more infrastructures is increasing day by day, the quantity of cement requirements is also increasing so replacing cement into green materials. The alternate green material for cement, high strength cement is made of Materials – Fly ash, Limestone, Silica fumes, Clay + Urease-Producing microorganisms – Sporosarcina pasteurii (bacteria inducing 100 % caco3) + Urea + Soluble calcium = Microbial-cement [15]. Permeation properties of concrete made with fly-ash and silica fume with the influence of ureolytic bacteria (Sporosarcina pasteurii) improves the permeability of concrete by improving its pore structure [11]. 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 an initial increase in pH in the entire medium, commences the growth of CaCO₃ crystals around the cell. Biochemical reactions (vide Eq.

1 2&3) in Urea-CaCl₂ medium to precipitate CaCO₃ at the cell surface can be summarized as follows [16]:



In this study, Cement is replaced by 40% fly ash, 25% limestone, 25% silica fumes and 10% clay in M40 grade of concrete and experiment were conducted and results are drawn, but there is a disadvantage in using fly ash as replacement of cement in concrete because the rate of strength developed is less compared to the ordinary Portland cement [14]. Fly ash and other cementing material increases ability of filling, passing, resistance to segregation [7]. Microbial-cementation and Bio-clogging process occurs where Bio clogging process is the production of pore filling material (self-healing process) shown in Figure 1.

Experimental Study on Microbial concrete with full Replacement of Cement by Fly Ash, Silica fumes, Clay, Limestone. There is a reduction in the raise of water by capillary action in microbial concrete as the size of pores is very less compared to the ordinary concrete [3]. Bacterial concrete is eco-friendly and it does not show any effect to living beings [2]. In the present work, an experimental work was carried out on bacterial concrete by adding microbial-cement. Tests were conducted to determine strength of both bacterial concrete and conventional concrete.

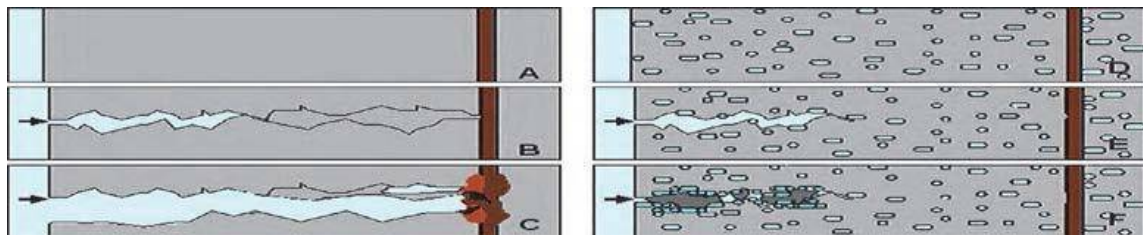


Figure 1 Bio-Mineralization Process of Conventional concrete A-C vs. Microbial concrete D-F

II. MATERIAL AND METHODS

In order to remediate concrete crack, it is necessary to either isolate calcium carbonate precipitating bacteria. The bacteria obtained by above sources are to characterized for calcium carbonate precipitation. The main significance of the study is to heal the cracks in structural elements by using the bacteria called *Sporosarcina pasteurii*. Synthetic polymers can also be used to treat the cracks which are harmful to environment, which needs to develop biological treatment techniques. Biological treatment is a type of technique in which bacteria is mixed with conventional concrete to heal the cracks in structural elements. Another important significance is to reduce the production of cement which contributes to air pollution by releasing CO₂. The materials used to prepare the microbial-cement are;

1. Fly ash



ash is a good material for wide range of application for manufacture of cement, substitute of cement in concrete. It is very suitable for cementitious / binding application. Fly ash, also known as Pulverized Fuel Ash

(PVA), is an industrial ash creates when coal is burned to create electric power. PFA, which is highly made up of Calcium oxide and Silicon dioxide, can be used as a substitute for Portland cement, or a supplement to it. The material can be used to bind or cement material together. Fly ash cement is also known as green concrete. Using fly ash cement in place of Portland cement uses less energy, requires less invasive

mining and reduces both resources consumption and CO₂. Table 1 shows the chemical properties of fly ash. **Table 1**

Chemical Properties of Fly Ash

S.No	Property % by mass	Fly Ash
1	SiO ₂ +Al ₂ O ₃ +Fe ₂ O	92.51
2	SiO ₂	53.26
3	MgO	0.78
4	Total Alkali (Na ₂ O+K ₂ O)	0.77
5	Sulphuric Anhydride	0.16
6	Al ₂ O ₃	28.65
7	Fe ₂ O ₃	5.61

2.2. Limestone



Limestone is a calcareous sedimentary rocks formed at the bottom of lakes and seas with the accumulation of shells, bones and other calcium rich goods, its major materials are the minerals calcite and aragonite, which are different crystal forms of CaCO₃ (Calcite). It is used as a building material, an essential component of concrete.

2.3. Silica-fumes



Silica fume, also known as micro silica, The main field of application is as pozzolonic material for high performance concrete it is sometimes confused with fumed silica (also known as pyrogenic silica, CAS number 112945-52-5).

2.4. Clay



One of the main being the fact that Clay as a building material is ideal for tropical conditions in our subcontinent. Clay is a healthy solution for modern day building construction

2.5. Bacteria

Bacteria species which called *Sporosarcina pasteurii* is isolated from soil and is collected from 3 places they are Beach coral side, Deposited Ariyallur and processed for screening

- Serial dilution
- Spread plate method
- Types of screening
- Purification
- Identification – Identified as *Sporosarcina pasteurii*
- Assay – 100% Calcium carbonate deposits

Sporosarcina pasteurii, was used in this study shown in Figure 2. The aerobic organisms is a moderately alkalophilic (growth optimum pH 9.25) and it was shown that sufficient activity for bio cementation could be cultivated in non-sterile conditions with a minimum of upstream and downstream processing. *pasteurii* was cultivated under aerobic batch conditions in 10 g/l yeast extract, 5 g/l NaCl, 25 mm CaCl₂ and 20 g/l urea. Medium pH adjusted before sterilization to 6.5 by 1 N HCl.

Urea/CaCl₂ was added post autoclaving by 0.22 filter sterilization to prevent chemical decomposition under autoclave condition. Conical flask was covered with a cotton plug and was enclosed with silver foil. Solution was sterilized using an autoclave for about 20 minutes at 121°C and 15lbs. In autoclave, water should be filled up to level 1. After sterilization, the solution was contaminant free and it was in clear orange colour



Figure 2 Bacteria – *Sporosarcina pasteurii* strain

III. CONCRETE MIX DESIGN

The selection of specific materials and proportions of concrete to achieve the goal of required properties with most economical use of materials such as strength, durability and workability. In present study mix design of M40 and proportion is 1:1.67:2.39 having water-cement ratio of 0.43 ratio.

Sporosarcina pasteurii bacteria were added to the concrete 10⁵ cells/ml to increase the strength and on other hand it reduces the internal cracks the concrete. When crack induced bio-mineralization process occurs with air or water

medium Microbial Induced Calcium carbonate Precipitates, which self-heals the concrete.

IV. RESULTS AND DISCUSSION

4.1. Compression Strength

The size of cubical moulds used in compression strength test was 150x150x150mm. Cubes are casted for 40% Fly ash, 25%Limestone, 25%Silica fumes and 10%Clay with Soluble calcium and with Aggregates, Water with bacterial solution (*sp.pasteurii*). Cubes are tested in compressive testing machine shown in Figure 3 after 7, 14 and 28 days curing period. After curing cubes are placed in Compression strength results are shown in below Table 2. From the experimental results, it has been observed that cement replaced with 40% Fly ash, 25%Limestone, 25%Silica fumes and 10%Clay with Soluble calcium and with bacterial solution (*sp.pasteurii*) showed compressive strength it has been observed that the microbial concrete showed more strength than conventional concrete.



Figure 3 Test Specimen of Compressive Strength Test

Table 2 Results of Compressive Strength Test

DESCRIPTION	COMPRESSIVE STRENGTH (N/mm ²)		
	7 DAYS	14 DAYS	28 DAYS
Microbial concrete	20.81	28.52	47.77
Conventional concrete	17.85	25.62	42.52

4.2. Split Tensile Strength Test

The sizes of cylindrical moulds are 150mmx300mm for tensile strength test. Cylinders were casted for 40% Fly ash, 25%Limestone, 25%Silica fumes and 10%Clay with Soluble calcium and with Aggregates, Water with bacterial solution (*sp.pasteurii*). Cylinders were tested in tensile strength machine after 7,14 and 28 days curing period. Tensile strength results are shown in below Table 3. From the experimental results, it has been observed that cement replaced with 40% Fly ash, 25%Limestone, 25%Silica fumes and 10%Clay with Soluble calcium and with bacterial solution (*sp.pasteurii*) showed tensile strength, it has been observed that the microbial concrete showed more strength than conventional concrete.

Table 3 Results of Split Tensile Strength Test

DESCRIPTION	SPLIT TENSILE STRENGTH (N/mm ²)		
	7 DAYS	14 DAYS	28 DAYS
Microbial concrete	3.89	4.14	5.41
Conventional concrete	2.18	3.52	3.89

4.3. Scanning Electron Microscope (SEM)



Scanning Electron Microscope is a type of electron microscope that produces image of a sample by scanning it with a focus beam of electron. The electrons interact with atoms in the sample producing various signals that contains information about the samples surface topography and composition. SEM can achieve resolution better than one Nano meter. Specimens can be observed in high vacuum, low vacuum, wet condition, environmental cell and at a wide range of cryogenic or elevated temperature. The SEM micrograph of control CM or CM mixed with 0.5, 1 and 1.5 OD bacterial cells up to 28 days are shown in Figure 4. From SEM observations, calcium carbonate (CC) precipitated by bacterial cells could be clearly distinguished within the pores of CM matrix; meanwhile, the CC phase isn't observed in control CM specimens made without any addition of bacterial cells. On the other hand, the precipitated calcium carbonate content increases with bacterial cells concentration.

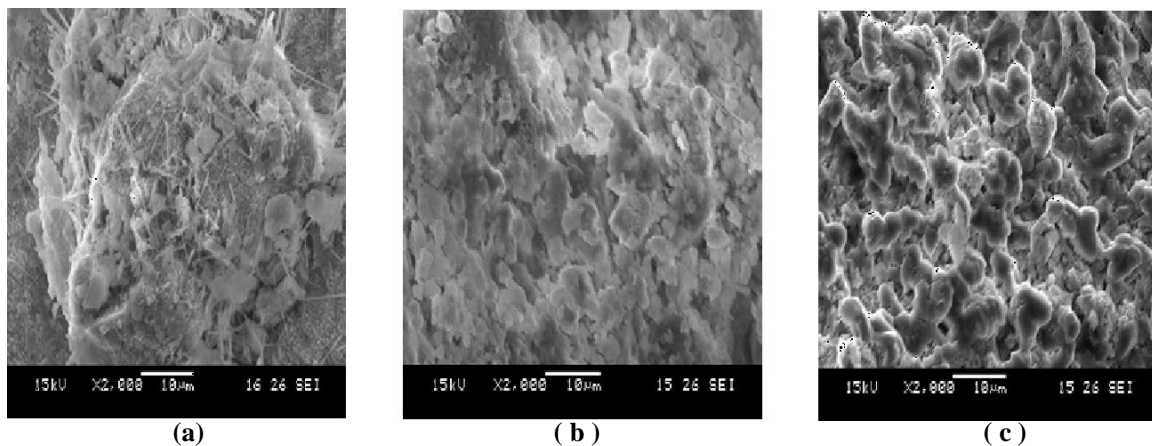


Figure 4 Scanning Electron Microscope Image of Microbial-Concrete with *Sp.pasteurii*. (a)7 days Image
(b) 14 days Image (c) 28 days Image

4.4. Energy Dispersive X-Ray Spectroscopy (EDAX)



Energy Dispersive X-ray Spectroscopy is an X-ray spectroscopic method for determining elemental

composition. When done in an SEM instrument signal can be acquired from a spot, an area, a line profile or a 2D map. It relies on an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique automatic structure allowing unique set up of peaks on its X-ray emission spectrum. To stimulate the emission characteristic X-ray from a specimen, a high energy beam of charged particles such as electrons and protons or a beam of X-rays is focused into the sample being studied. The number and energy of the X-rays emitted from a specimen can be measured by an energy dispersive spectrometer. EDS allows the elemental composition of the specimen to be measured. The bacterial cell with rod shape is observed as a hole distinguished inside the surface of spherical calcite crystal. EDAX analysis indicated that the new phase precipitated, by bacterial cells, in CM matrix is calcium carbonate shown in Figure 5.

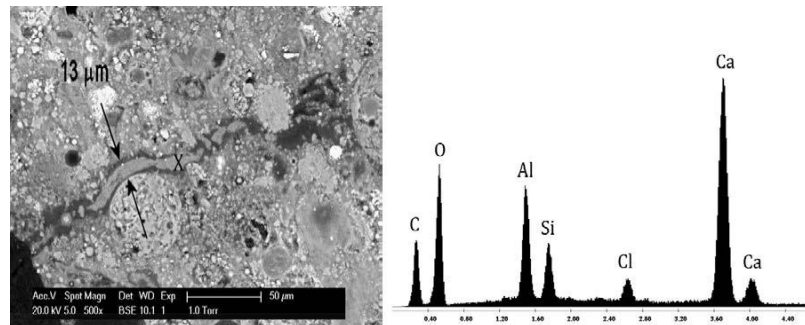


Figure 5 Energy dispersive x-ray spectrum image for Microbial-cement with *Sporosarcina pasteurii*

V. CONCLUSION

- Microbial concrete is advantageous than conventional concrete due to its self-healing capacity and eco-friendly nature.
- Cement is replaced by 40% Fly ash, 25% Limestone, 25% Silica fumes and 10% Clay with Soluble calcium and with bacterial solution (*Sporosarcina pasteurii*) which has same physical and chemical property as Cement is known as Microbial-cement.
- Microbial-cement gives rise to Green concrete Technology, which has low emission of CO₂ and CO directly or indirectly in the environment.
- The compressive strength of concrete increased when cement is replaced by concrete for M40 grade of concrete at 100% replacement of cement by microbial cement the concrete attained 10.9% maximum compressive strength for M40 grade of concrete. The split tensile strength of concrete is also increased by 28% when cement is replaced by microbial cement.
- A mix design for M40 grade concrete has been chosen for better performance. The Compressive and Tensile strength were conducted on hardened concrete and compared with the controlled and microbial concrete, it has been observed that the microbial concrete showed more strength than conventional concrete.
- Calcite precipitate of bacteria indirectly increases the strength of concrete by filling the voids.

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