MICROBIAL CONCRETE: A MULTI-PURPOSE BUILDING MATERIAL-AN OVERVIEW

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ABSTRACT

Microbial concrete has emerged as a novel technique in recent years. It can be used for various purposes, amongst which remediation of cracks in concrete is the primary one. It can be used as an alternative to surface treatment and water purifier. An overview of these uses of microbial concrete is presented here. Various factors which cause cracks in concrete as building material, have been discussed. Conventional remedies and non-conventional remedies for concrete crack remediation are discussed in detail. In microbial concrete, microbes help in mineralization which induces calcium carbonate precipitation which is used as non-conventional remedy to remediate cracks in building materials. Various microbes which helps in calcium carbonate precipitation have been discussed in brief along with their effect on various properties of concrete which determine the efficiency of concrete are also discussed.

KEYWORDS: *Microorganism, Concrete crack remediation, Bacillus-Pasteurii, Compressive strength, Durability.*

I. INTRODUCTION

Concrete is one of the most important and widely used building materials being used in many types of engineering structures. The economy, the efficiency, the strength and its ability to be moulded to any shape make it an attractive material for a wide range of structural applications. At present, concrete is the largest consumed man-made material. But despite of its wonderful properties it has few drawbacks amongst which the main one is its vulnerability to cracking. Cracking of concrete is a common phenomenon. There are various factors such as natural, physical, chemical and biological factors, which cause cracks in concrete. Natural Factors, such as weathering, faults, land subsidence, earthquakes and human activities. Weathering induces increased porosity, structural weakening of surface layers, unattractive appearance and ultimately reduces the service life of the structures. Without immediate and proper treatments, cracks in concrete structures tend to expand further and eventually require costly repair. Even though it is possible to reduce the extent of cracking by available modern technology, remediation of cracks in concrete has been the subject of research for many years. Keeping all these points in consideration, we need such technique(s) which has the potential to contribute both better environmental sustainability as well as enhanced mechanical and durability concrete properties. Microbial concrete has emerged as a new technique in recent years which can be used for various purposes, amongst which remediation of cracks in concrete is the primary one. It can be used as an alternative to surface treatment and water purifier.

1.1. Micro-organism

Bacteria are the most diverse and abundant group of organisms on Earth. Bacteria inhabit practically all environments where some liquid water is available and the temperature is below +140 °C. They are found in sea water, soil, air, animals' gastrointestinal tracts, hot springs and even deep beneath the Earth's crust in rocks.

Bacteria are often dismissed as germs, but help us do a range of useful things like production of antibiotics, nitrogen fixation, live in the guts of animals (including humans) or elsewhere in their bodies, or on the roots of certain plants. Bacteria are of great importance because of their extreme flexibility, capacity for rapid growth and reproduction. A micro-organism is an organism that is microscopic (too small to be seen by the naked human eye). Micro-organisms are incredibly diverse and include bacteria, fungi, archaea, and protists, as well as some microscopic plants and animals such as plankton, and popularly-known animals such as the planarian and the amoeba.

1.2 Microbial concrete and its applications

Microbial or bacterial concrete is prepared by mixing a cement paste containing microbial cells along with a calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus are added to the ingredients of the concrete in particular ratio. Apart from its other wonderful properties, due to its major property of crack remediation or self-healing, it is also known as self-healing concrete. This technology of using microbes for calcium carbonate deposition or microbial concrete, called as Microbially induced calcium-carbonate precipitation (MICCP), can be used for solving various durability issues of construction materials. Due to natural capability to precipitate calcite continuously bacterial concrete is also called a ‘SMART BIO MATERIAL’. Several different microbial groups contribute in the precipitation of mineral carbonates in various natural environments.

Microorganisms which are present in nature in abundant, are the resource for significant production of bacterial calcium carbonate crystals/ calcite/ concrete. As the micro-organisms can penetrate and reproduce themselves in soil or any such environments, there is no need to disturb the ground or environment unlike that of cement.

The use of microbial concrete in Civil Engineering has become increasingly popular. From enhancement in durability of cementious materials to improvement in sand properties, from repair of limestone monuments, sealing of concrete cracks to highly durable bricks, microbial concrete has been successful in one and all. This technology also offers the advantage of being novel and eco-friendly. This special kind of concrete has multiple usage. According to its different usage it can be classified as following:

- Microbial concrete as concrete crack remediation/healing.
- Microbial concrete as an alternative surface treatment for concrete.
- Microbial concrete as antifungal cement mortar.
- Microbial concrete as water purifier or bacterial cleaner/builder.
- Microbial concrete as restoration material for stone building.

Microbially induced precipitation has been investigated by many researchers for its potential to improve the durability of construction materials such as cementitious materials, sand, bricks and limestone. This technology has been investigated for its potential to make concrete which can be used for different purposes. Many research groups investigated this for filling of pores and cracks in concrete (Bang et al., 2001; Ramakrishnan et al., 2007; De Muynck et al., 2008) while few have worked on cement mortar cubes (Achal et al.,2011b), as an alternative to surface treatment (De Muynck et al., 2008), sand consolidation and limestone monument repair (Stocks – Fischer et al., 1999; Bachmeier et al., 2002; Dick et al., 2006; Achal et al., 2009b), reduction of water and chloride ion permeability in concrete (Achal et al., 2011a) and for making water purifying concrete .

1.3 Various microbes used in microbial concrete

Various microbes used in microbial concrete, from literature review are tabulated in Table 1.

Table.1: Various types of microbes used in concrete

Sr. No.	Type of Microbial Concrete	Name of the Microbe	Reference
1.	Microbial concrete as crack healer	1.Sporosarcina pasteurii 2 Bacillus pasteurii 3.Bacillus pasteurii 4.Bacillus sphaericus	Bang et al. (2001) Ramachandran et al. (2001) Ramakrishnan et al. (2007) De Belie et al. (2008)

		5.Bacillus sphaericus	De Muynck et al. (2008), (2010)
2.	Microbial concrete as Self Healing	1.Bacillus pseudifirmus 2. Bacillus cohnii	Jonkers et al. (2007)
3.	Microbial concrete as surface treatment	1. Bacillus sphaericus 2. E. coli.	De Muynck et al. (2007) De Muynck et al. (2008)
4.	As Cement mortar and Concrete	1.Bacillus cereus 2.Bacillus sp. CT-5 3.Bacillus pasteurii 4.Shewanella 5.Sporosarcina pasteurii	Le Metayer- Leverel et al. (1999) Achal et al. (2011b) Ramachandran et al. (2001) Ghosh et al. (2005) Achal et al. (2011a)
5.	Microbial concrete as water purifier	1. Bacillus Subitilis 3.Bacillus thuringiensis	2. Bacillus phaericus 4.Thiobacillus

II. MICROBIAL CONCRETE FOR CONCRETE CRACK REMEDIATION

Natural processes, such as weathering, faults, land subsidence, earthquakes and human activities create cracks and fractures in concrete structures. Weathering induces increased porosity, structural weakening of surface layers, unattractive appearance and ultimately reduces the service life of the structures. Concern about the degradation of concrete and the economic impact of the maintenance and repair of concrete structures have drawn the attention to processes of concrete deterioration, and to the methods to slow down or even to eliminate concrete degradation (Hewlett et al., 1990). Without immediate and proper treatments, cracks in concrete structures tend to expand further and eventually require costly repair. Even though it is possible to reduce the extent of cracking by available modern technology, remediation of cracks in concrete has been the subject of research for many years.

Concrete Crack Remediation with Conventional Solutions and their disadvantages: There are so many synthetic agents which are used to avoid any kind of cracks and fissures in the concrete structures. These are also used in repair applications such as the bonding of fresh concrete, sprayed concrete or cement/sand repair mortar to hardened concrete. Bonding agents are natural, compounded or synthetic materials used to increase the joining of individual members of a structure without employing mechanical fasteners. The main types of bonding agents used in the construction industry to remediate cracks and to hardened structure are:

- Latex emulsions
- Epoxy bonding agents
- Surface treatments with silanes or siloxanes (water repellants) or pore blockers.

These conventional means of protection show a number of disadvantageous aspects such as :

- weak bonding with surface
- different thermal expansion coefficient of treated layers
- degradation over time
- need for constant maintenance and costly too.
- some solvents contributes to pollution (Camaiti et al., 1988; Perez et al., 1995; Metayer-Levrel et al., 1999)
- Styrene butadiene latex coagulate if subjected to high or freezing temperatures.

Cracking in concrete structures continues over a long period of time, so these kinds of treatment are required repeatedly. Moreover, these are not the permanent solution. Hence, in such situations, a way in the form of **self-healing materials** should be found out seal the cracks automatically.

2.1 Microbial concrete as non-conventional crack healer

This is a novel technique in remediation of cracks in concrete in which microbiologically induced calcite precipitation (MICP) is used. It is the process in which living organism (microbes) form organic solid is used in building materials for concrete crack remediation. There are various bacterial species which have been reported in increasing the strength of building materials and concrete crack remediation.

Microbial concrete biologically build limestone to heal cracks that appear on the surface of concrete structures. The bacteria group *Bacillus*, along with a calcium-based nutrient (known as calcium lactate), nitrogen and phosphorus, are added to the ingredients of the concrete when it is being mixed. These self healing agents can lie dormant within the concrete for a very long period but when a concrete structure is damaged and ingress of water starts to percolate through the cracks in the concrete, the bacteria start growing on contact with the water and nutrients. Subsequently oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone which solidifies on the cracked surface, thereby sealing it up.

There are various bacterial species which have been reported in increasing the strength of building materials and concrete crack remediation. Bacillus Pasteruii is a common soil bacteria which can continuously induce the precipitation of calcite layer which is highly impermeable over the surface of already existing concrete layer. Due to natural capability to precipitate calcite continuously bacterial concrete is also called a 'SMART BIO MATERIAL'. Several different microbial species participate in the precipitation of mineral carbonates in various natural environments.

It has been known that calcite (calcium carbonate) has values of technical and industrial applications for the preservation, remediation and restoration of buildings, calcareous stone statuaries and historic monuments. Calcite is needed in high purity and good coherency for better restoration. However, it is a very laborious and expensive process to obtain the highly pure and coherent calcite from natural sources, such as shell crust. Thus, bacterially induced carbonate precipitation has received attention as an environment-friendly method of protecting decayed ornamental carbonate stone.

2.2 Possible biochemical reactions

Bio-mineralisation is defined as a biologically induced precipitation in which an organism creates a local micro-environment with conditions that allow optimal extracellular chemical precipitation of mineral phases (Hamilton at al., 2003).

In natural environments, chemical $CaCO_3$ precipitation ($Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3\downarrow$) is accompanied by biological processes, both of which often occur simultaneously or sequentially. This microbiologically induced calcium carbonate precipitation (MICCP) comprises of a series of complex biochemical reactions (Stocks-Fischer et al.,1999). As part of metabolism, *B. pasteurii* produces urease, which catalyzes urea to produce CO_2 and ammonia, resulting in an increase of pH in the surroundings where ions Ca^{2+} and CO_3^{2-} precipitate as $CaCO_3$. POSSIBLE BIOCHEMICAL REACTIONS in urea-$CaCl_2$ medium to precipitate $CaCO_3$ at the cell surface can be summarized as follows.

Ca^{2+} + Cell → Cell-Ca^{2+} .... (1)

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

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

Hammes et al., (2002) studied the sequence of events taking place during ureolytic calcification emphasizing the importance of pH and calcium metabolism during the process shown in Figure1. The primary role of bacteria has been ascribed to their ability to create an alkaline environment through various physiological activities.

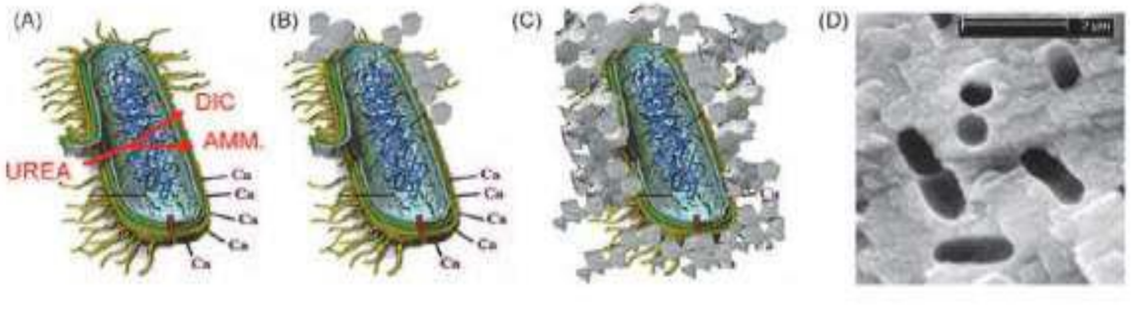


Figure 1. Calcite precipitation by bacterial cell (Hammes, F. et al.,2002)

Figure1 shows Simplified representation of the events occurring during the microbially induced carbonate precipitation. Calcium ions in the solution are attracted to the bacterial cell wall due to the negative charge of the latter. Upon addition of urea to the bacteria, dissolved inorganic carbon (DIC) and ammonium (AMM) are released in the micro environment of the bacteria (A). In the presence of calcium ions, this can result in a local super saturation and hence heterogeneous precipitation of calcium carbonate on the bacterial cell wall (B). After a while, the whole cell becomes encapsulated (C). Limiting nutrient transfer, resulting in cell death. Image (D) shows the imprints of bacterial cells involved in carbonate precipitation.

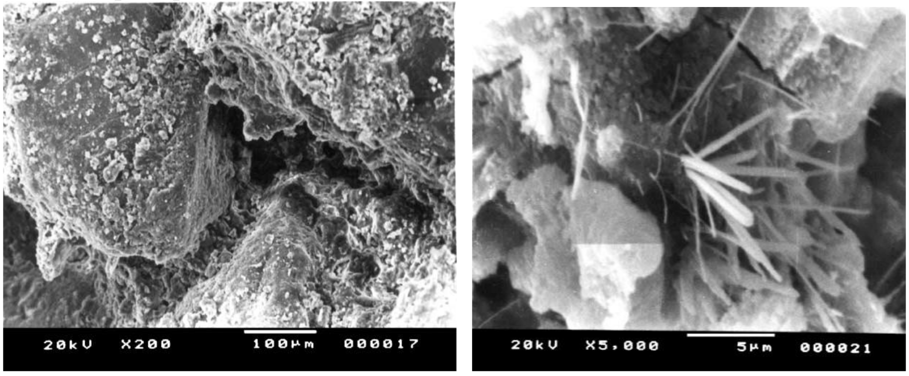
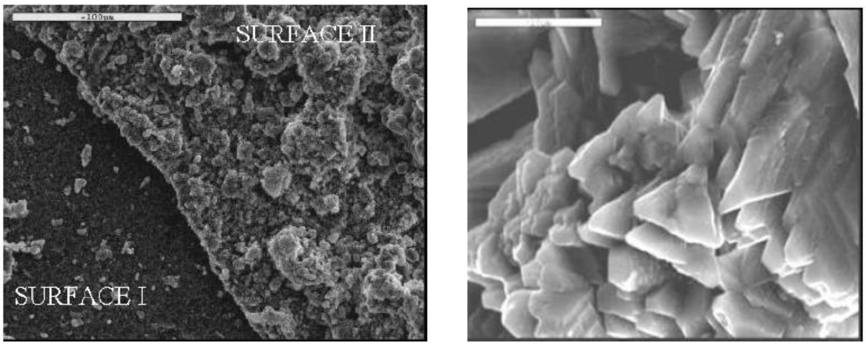


Figure 2. (a) SEM micrograph of mortar without any microorganisms (b) mortar with anaerobic microorganisms of 105/ml cell concentration (P Ghosh et al., 2005)

SEM Investigation (Ramakrishna et al.,2005) : Microbial calcite precipitation was quantified by X-ray diffraction (XRD) analysis and visualized by SEM. The specimens with bacteria did not 2.4. develop any micro cracks, as they did not expand much unlike control specimens when subjected to alkali aggregate reactivity, sulphate attack, drying shrinkage and freeze-thaw. Figure 1 shows that a new layer (Surface II) was formed over the surface of the cement mortar beam (Surface I). The elemental composition of surface-I was found to be characteristic of cement material, and the elemental composition of surface II, was found to be predominantly calcite material, which formed an impermeable layer and increased the durability performance. Magnified image of calcite crystals found on the surface II of the bacterial specimen, subjected to freeze thaw, is shown in Figure 2 Bacteria were found in intimate contact with the calcite crystals Figure 3. Rod-shaped impressions, consistent with the dimensions of B. pasteurii were found in the calcite crystals, which formed on the surface of the specimens in Figure 4.

2.4.Uses

- For remediation of cracks in concrete.
- For repairing structure of historical importance to preserve aesthetic value when conventional techniques are not recommended



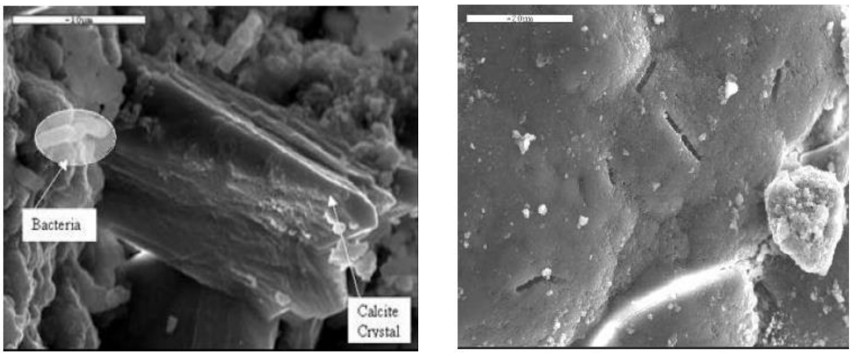


Figure 3 (a) A new calcite layer (Surface II) formed over the (surface I) of the cement mortar (b) Magnified image of calcite crystals on the surface II of the bacterial specimen (c) Development of calcite crystals at higher magnification (d) Rod-shaped impressions, consistent with the dimensions of B. Pasteurii spread around the calcite crystals

2.4 Effects of microbes on various properties of concrete used as crack remediation

2.4.1.Compressive strength

Ramachandran et al., (2001) studied the effects of microbes on compressive strength of cement mortar cubes at age of 7 and 28 days. They found that inclusion of microbial biomass (Bacillus Pasteurii) enhanced the compressive strength. They used live and killed cells of different concentrations of Bacillus Pasteurii and found that the live cells, at lower concentrations, increase the compressive strength of cement mortar with a longer incubation period. Their findings have been presented in Table 2. These findings are very important with respect to concrete crack remediation. Increase of compressive strength of Portland cement mortar cubes with different depths in presence of B.Pasteurii has been shown on figure given below:

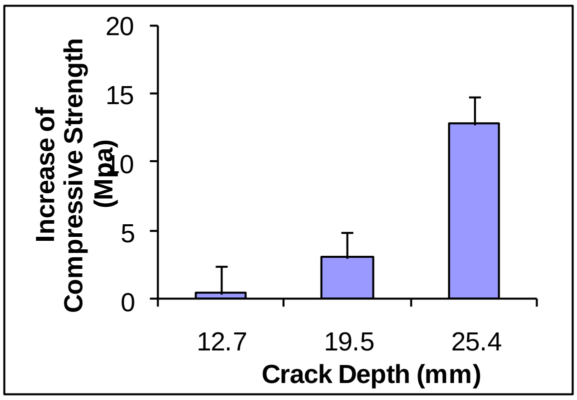


Figure 4 Increase of compressive strength of Portland cement mortar cubes with different depths in presence of B.Pasteurii (Ramachandran et al., 2001)

P. Ghosh et al., (2005) studied the effects of addition of anaerobic microorganism, Shewanells species on compressive strength of cement sand mortar. They found that the strength of mortar cubes increased at all levels of anaerobic microbe addition. They reported 25% increase in 28 days compressive strength of cement mortar was achieved with the addition of about 10,0000 cells/ml of mixing water. (refer table 3).

Table 2. Compressive strength values of 7 and 28 days tests with Portland cement mortar cubes mixed with biomass (Ramachandran et al., 2001)

	Bacillus pasteurii, cells/cm^3	**7-day compressive strength, MPa**		**28-day compressive strength, MPa**	
		Average	**Standard deviation**	*Average*	**Standard deviation**

Control	0	47	1.38	55	1.27
Live	3.8 X 10^3	55	2.39	62	3.23
	3.8 X 10^s	54	1.55	63	1.97
	3.8 X 10^7	57	1.27	65	0.87
Killed	3.8 X 10^3	53	3.73	56	2.36
	3.8 X 10^5	59	3.46	55	2.42
	3.8 X 10^7	60	1.81	61	0.92
Live	7.6 X 10^3	46	2.08	65	0.81
	7.6 X 10^5	50	2.73	55	2.33
	7.6 X 10^7	55	1.28	55	0.44
Killed	7.6 X 10^3	57	1.47	59	3.19
	7.6 X 10^s	61	2.88	56	2.57
	7.6 X 10^7	66	1.41	58	0.79

Table 3 Effect of the anaerobic microorganisms addition on mortar strength (Ghosh et al., 2005)

Cell conc./ ml of water	**Average mortar compressive strength in MPa**					
	7 days		**14 days**		**28 days**	
	Strength ±S.D	**% Increase relative to control**	**Strength ±S.D**	**% Increase relative to control**	**Strength ±S.D**	**% Increase relative to control**
Nil	12.60±0 .47	-	16.00 ±0. 81	-	23.13±0. 23	-
10	12.74±0.89	1.11	16.21 ±0.22	1.31	24.21 ±0. 43	4.66
10^2	12.87 ±0 .46	2.14	16.44 ±0. 38	2.75	25.00 ±0. 88	8.08
10^3	12.98±0 .81	3.01	16.87 ±0. 64	5.43	25.40±0. 84	9.81
10^4	13.4±0. 53	6.34	17.10 ±0.37	6.87	25.44 ±0. 97	9.98
10^5	14.70±0 .74	16.67	19.50 ±0. 42	21.87	28.98 ±0. 86	25.29
10^6	13.80±0 .58	9.52	17.50 ±0. 81	9.38	26.52 ±0. 27	14.65
10^7	13.00±0.23	3.17	17.00 ± 0. 45	6.25	25.69 ± 0.74	11 .06

Ramakrishna et al., (2005) reported that compressive strength of concrete with B-Pasteurii as microbes, had marginal (5 to 10%) increase in strength (in case of BU &BP bacterial suspended in urea $Cacl_2$, Bacteria suspended in phosphate buffer when conc. with BW (Bacteria suspended in water) had marginal decrease in strength(10%) when compared to controlled concrete samples.

2.4.2 Weight increase

(De Muynck et al., 2005) The influence of w/c ratio and calcium source on amount of carbonate deposited was measured by mean of weight increase of specimens with w/c 0.5 & 0.7 after treatment with breaking two different nutrient , weight decrease was found in specimens.

2.4.3 water absorption

To determine the increase in resistance towards water penetration a sporptivity test was carried out by **De Muynch et al., (2008)**. Absorption of bacteria and precipitation of carbonate crystals resulted in weight increase of the mortar specimens. The most pronounced reduction in water absorption compared to untreated samples was reached for the most porous mixture w/c (0.7) .

2.4.4 Shrinkage

Ramakrishna et al.,(2005) investigated the effect of bacteria suspended in different mediums on the drying shrinkage of the concrete and reported that at the end of 28 days beams with bacterial concentration of 1 x 10^6cells/ml, 1 x 10^7 cells/ml, and 1 x 10^8 cells/ml had 13%, 20%, 34% less shrinkage deformations respectively than that of the control beams.

The effect of different concentrations (1 × 10^6 cells/ml, 1 × 10^7 cells/ml and 1 × 10^8 cells/ml) of bacteria suspended in phosphate-buffer on the drying shrinkage of the concrete beams was studied and it was found that at the end of 28 days the beams with bacteria suspended in water, urea-$CaCl_2$ and phosphate-buffer had 3%, 15%, and 19% less shrinkage deformations respectively than that of the control beams.

2.4.5 Resistance towards alkalinity

(Ramakrishna et al., 2005) The effect of bacteria suspended in different mediums on the alkali aggregate reactivity of concrete beams At the end of 14 days beams made with bacteria suspended in water, urea-$CaCl_2$ and phosphate-buffer had 7%, 18% and 30% less mean expansions respectively than that of the control beams. At the end of 14 days beams made with bacteria suspended in water, urea-$CaCl_2$ and phosphate-buffer had 7%, 18% and 30% less mean expansions respectively than that of the control beams. The effect of different concentrations of bacteria (1 x 10^7 cells/ml, 1 x 10^8 cells/ml and 1 x 10^9 cells/ml) suspended in phosphate-buffer on the alkali aggregate reactivity of concrete beams.

2.4.6 resistance towards sulphate attack

(Ramakrishna et al.,2005) The effect of different concentration of bacteria (1 × 10^8 cells/ml, 8.6 × 10^8 cells/ml and 1 × 10^9 cells/ml) suspended in phosphate-buffer on sulfate attack resistance of concrete beams. Beams with bacterial concentration of 1 x 10^8 cells/ml, 8.6 x 10^8 cells/ml, 1 x 10^9 cells/ml had 9%, 22%, and 30% less mean expansions respectively than that of the control beams.

III. MICROBIAL CONCRETE AS SURFACE TREATMENT

Surface treatments play an important role in limiting the ingress of water and consequently of detrimental components – into concrete. Many of the physical and chemical deterioration mechanisms of concrete are related to aggressive substances present in aqueous solution. Therefore an important measure to protect concrete against damage is diminishing the uptake of water (Bashir et al., 2001). Undoubtedly, broad a range of products are available in the market for protection of concrete surfaces. Several of these products are organic coatings consisting of volatile organic compounds. The air polluting effect of these compounds during manufacturing and coating has led to the development of new formulations such as inorganic coating materials. Traditional inorganic coatings consist of calcium-silicate compounds, which exhibit a composition similar to cement (Moon et al., 2007). Surface treatments with water repellants like epoxy injections, with pore blockers and various synthetic agents like silanes or siloxanes are also available today, but with a number of disadvantages like degradation with time, need for constant maintenance and environment pollution (De Muynck et al., 2006).

These conventional means of protection show, however, beside their positive influences also a number of unfavourable aspects such as:

- different thermal expansion co-efficient of the treated layers;
- degradation over time and
- the need for constant maintenance.

Within this framework, bacterial induced carbonate mineralization has been proposed as a novel and environmentally friendly strategy for the protection and remediation of stone and mortar.

Muynck et al. (2007) proposed a bacterial induced carbonate mineralization as a novel and environmental friendly strategy for the protection of stone and mortar due to the negative side-effects of some of the conventional techniques. They reported the effects of bacterial CaCO3 precipitation on

parameters affecting the durability of concrete and mortar. Pure and mixed cultures of ureolytic bacteria were compared for their effectiveness in relation to conventional surface treatments. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of permeability towards gas and capillary water uptake. This bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surfaces. The use of pure cultures resulted in a more pronounced decrease in uptake of water, respectively less pronounced change in the chromatic aspect, compared to the use of mixed ureolytic cultures as a paste. The results obtained with cultures of the species Bacillus sphaericus were comparable to the ones obtained with conventional water repellents.
The process of surface treatment resulted in decreased gas permeability for all w/c ratio specimens. The process of deposition of calcite layer contributed to a large extent in the overall decrease in the gas permeability. Muynck et al.,(2007) reported that the deposition of a layer of calcite resulted in a decrease in gas permeability. Muynck et al.,(2008) reported that the bio-deposition treatment resulted in an increased resistance of mortar specimens towards carbonation, chloride penetration and freezing and thawing.

3.1 Microbes used

i) Bacillus Sphaericus
ii) Ureolytic mixed cultures

IV. MICROBIAL CONCRETE IN RESTORATION OF STONE BUILDINGS

Many ancient monuments have been built with tough carbonate stones. With the passage of time, the calcareous matrix of the stone shows progressive increase in its porosity and a significant decrease of its mechanical characteristics due to the calcite leaching process. This leads to breakage of the materials into smaller particles and finally back into constituent minerals. Numerous conservative treatments are available with inorganic and organic products which can slow down the deterioration process of monuments. However, they offer several drawbacks due to their chemical composition and thermal expansion coefficient as they differ a lot from that of the stone. There is long-term incompatibility of the substrate and the new cement used for consolidation) and the plugging of pores in the treated material induced by the new cement or protective layers. These products are also formulated and applied in solvents at very low concentration that lead to huge waste of organic solvents in the environment. Moreover, their efficiency is inconsistent and in certain cases, they can have a harmful effect for the conservation of the stone material itself. Shortcomings of conventional techniques have drawn the attention to bacterially induced carbonate precipitation for reducing the permeation properties and thereby, enhancing the durability properties of ornamental stone. Various researchers have applied this technology for remediation of stone (Le Me´tayer et al., 1999; Dick et al., 2006; Tiano et al., 1995, 1999, 2006).

V. MICROBIAL CONCRETE AS WATER PURIFIER

A concrete product prepared by mixing a cement paste containing microbial cells in particular ratio by mass respectively of 0.1 to 50, 0.1 to 60, 0.1 to 80 with crushed stone and water, then shaping and hardening the mixture. Crushed stone have a diameter of 2.5 to 10 mm in range of 1500 to 1950 kg are mixed with cement paste in the range of 250 to 300 kg. This cement paste containing microbial cells is useable in producing concrete effective for water purification.

5.1 Microbes

Microbes which have used to create excellent water purification effect with long for persistence comprises of:

1. Bacillus Subtilis
2. Bacillus Thuringiensis
3. Bacillus Sphaericus.

These cells can be readily extracted from soil and cultured.

Ratio : 0.1 to 50

Cement paste may comprise (but not limited to) traditional cement (normal P C or blast furnace slag cement). The above mentioned three kinds of microbial cells have sufficient resistance against strong alkalinity even after they are mixed in the cement paste and against high temperature during production process.

5.2 Effects

Concrete plate (microbial conc.) purifies water impurities after some time (2 weeks), black muddy colour is changed to clean colour in two months. It also eliminate smell of water. B.O.D. of 1400 can be reduced to B.O.D. of 1.4.

5.3 Uses

- Useable as water purifier tank walls.
- Floor lining of a water purifying facility in homes, industrial plants.
- The cement containing microbial cells can be effectively used for purifying water such as river water or lake water and in particular can be effectively used at a location where water flows at a low rate with stagnation.

5.4 Industrial applicability

River, lake, pond, old fashioned toilet or drainage canal a fountain pond in parks, or bottom walls of swimming pools, banks of river, chicken farms, cow bards etc.

VI. CONCLUSIONS

Microbial concrete technology has emerged as a better technology than many conventional technologies because of its wonderful properties such as its eco- friendly nature, self-healing abilities and ability to increase durability of various building materials. Various investigations done by researchers have improved the understanding on the possibilities and limitations of biotechnological applications on building materials. Improvement of compressive strength, reduction in permeability, water absorption, reinforced corrosion have been seen in different cementitious and stone materials. This method of cementation is quite easy and convenient for practice.

This technology will provide the foundation for high quality structures but to address following mentioned issues, more work is required to improve the feasibility of this technology from practical viewpoints.

- Issues related to its cost effectiveness and quality are still to be addressed.
- Detailed studies are required to focus on different types of nutrients and metabolic products used for growing calcifying microorganisms.
- More work is required to be done on the retention of nutrients and metabolic products in the building material.
- The effect of acidic precipitation on the durability of the bio-deposition treatment needs to be investigated because calcium carbonate is dissolved in acidic environments. In future research the durability of the calcite layer under varying conditions is required to be investigated.

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