A Study of Microorganism (Bacteria) on Concrete Strength and Durability: A Critical Review

G.T. Suthar
[1]*PG Student, Government Engineering College, Dahod-389151, India*

Dr. K.B.Parikh
Assistant Professor, Department of Applied Mechanics, Government Engineering College, Dahod-389151, India

Abstract- The purpose of this research is to study the behavior of microorganism Bacillus Subtilis for enhancement of strength in cracked concrete specimen. In concrete, crack is very important phenomenon due to having low tensile strength and stress which cause settlement, shrinkage and expansion in concrete. Without any treatment and precaution crack is expand further more and require expensive repair. In this paper the bacillus subtilis, a gram positive bacteria was used to induced the precipitation of calcite. This procedure is incredibly applicable due to various fact like it is pollution free and natural. The comparative result is considered for evaluation of strength and durability with addition of bacteria in cracked specimen. Scanning electron microscope (SEM) was used to check the role of microorganism precipitation in improving the strength and durability of concrete.

Keywords – Bacterial concrete, Bacillus Subtilis, Strength, Durability, Microorganism

I. INTRODUCTION

There are some investigation on the topic of microbially induced carbonate precipitation (MICP) has been conducted in the past. Microbially induced calcite precipitation is natural process and which is comes from earth since ancient time. The minerals which formed from calcium and carbonate ions. Just because of the calcium carbonate mineral are homogeneous and environmental friendly, it can use for healing of crack in concrete specimen. Crack is one of the most vulnerable problem for concrete structure because of crack in concrete water and other mineral seep through crack and caused to corrosion and other defect. The material which form with addition of bacteria in concrete has successively remediate crack and this process is mostly useful because of bacteria are safe and environmental friendly. Furthermore the cell wall of bacteria is anionic, calcite precipitation on the surface of the wall is substantial, and thus the cell wall become crystalline and eventually they filled the pores and crack in concrete. This technique is more impressive for achieving high compressive strength of concrete.

The effect of durability is also affected due to crack in concrete. If micro crack grow and reach at the level of reinforcement, the possibility of developing the corrosion and damage are more. In the case of other type of healing material there are some disadvantages like thermal expansion, temperature gradient, shrinkage, cost, is more compared to bacterial concrete, hence this technique is useful and prove to be economical and unhygienic.

II. LITERATURE REVIEW

V. Ramakrishnan (2001) et al. purposed the technique in remediating crack and fissure by using microbiologically induced calcite precipitation (MICP). MICP is the technique called biomineralization by which living organism form inorganic solid. They use bacillus pasteruii as a microbial sealant. They found that the MICP is cost effective and it is natural process for development of calcite. For improvement of strength and stiffness this technique is used. The durability is improved with addition of cells concentration of bacteria in concrete. They quantified calcite precipitation by XRD analysis and visualised by scanning electron microscope. They conclude that the presence of bacteria in different medium increase the shrinkage and other chemical attack. Authors used bacillus pasteruii as a microbial sealant.

E Schlangen (2010) et al, studied the overview of self-healing techniques in three different materials. The first application is using Bacteria to precipitate calcite in cracks in concrete. With this method relatively large cracks in reinforced concrete can be filled. The method does not lead to strength improvements of the structure, but by filling the crack, the path to the reinforcement is blocked. Herewith the ingress of liquids and ions that start reinforcement corrosion is stopped and thus the durability of the structure is enhanced. Furthermore this method is useful for water retaining structures. Cracks can be filled in this way and leakage can be stopped. Especially in underground structures were repair is difficult or impossible Bacterial concrete has a big future. In the second application SHCC (strain hardening cementitious composites) materials are studied, which have already a high potential for self-healing because of their small crack widths. New additions, like microfibers and SAP (Super Absorbent Polymers) seven promote this self-healing capacity further. The third application is for asphalt concrete in which the self-healing capacity is enlarged by using encapsulated oil and micro-steel fibres. The latter approach has been proven to work in the laboratory and will be applied in a real road in the Netherlands in 2010.

Kartik M. Gajjar (2013), Purposed to use the bacteria named bacillus lentus a common soil bacterium to induce calcite precipitation. The effectiveness of this technique has been evaluated by comparing strength and durability of cracked specimens remediated with bacteria and those of the control specimens. The experiment study can found that with addition of bacteria (Bacillus Lentus) in cracks improves the compressive Strength is around 17.3% at 28th day and 17.6% at 56th day. The flexural strength not much increase in 28th and 56th day. In durability test of concrete cube without crack and bacteria, with crack without bacteria, with crack and bacteria immerse in 3.5% MgSO4, The percentage weight loss respectively are 1.31%, 1.95%, 0.66% 1.78%, 0.62%, 1.67% and 0.59%.it show that the percentage loss in with crack and bacteria is less as compared to without crack and bacteria and with crack and without bacteria concrete cubes. The percentage strength loss are 3.07%, 4.31%, 3.22%, 4.77%, 3.42%, 5.29% and 3.79%. It shows that strength loss percentage in with bacteria and crack is less compared to with crack and without bacteria but larger than without crack and bacteria concrete cubes.

Mayur Shantilal Vekariya (2013) presented that the study of bacterial concrete with its advantage, disadvantages and the different application of calcite producing bacteria for improving the performance of concrete. They studied the latest microbially induced material for enhancement of concrete strength.On the basis of study they found that the microbial activity is most economical, self-repairing building material. Work of various researchers has improved our understanding on the possibilities and limitations of biotechnological applications on building materials. Enhancement of compressive strength, reduction in permeability, water absorption, and reinforced corrosion has been seen in various cementitious and stone materials. Cementation by this method is very easy and convenient for usage. This technique is desirable but it require more research study and the microorganism is require some favourable condition.

Navdeep Kaur Dhami (2012) et al, purposed to investigate the potential of Bacillus megaterium to produce calcite and improve properties of Fly ash bricks and Rice husk ash bricks. They found that the treated bricks have considerably showed improved compressive strength and reduction in frost attack, water absorption due to calcite deposition on the surface and voids of bricks. Scanning electron micrographs revealed extracellular deposition of calcite crystals by the bacteria on the surface of the bricks. X-ray diffraction and energy dispersive X-ray analysis confirmed the precipitates formed as $CaCO_3$ are calcite crystals. These observations suggest that this technology has the potential of producing durable and eco-friendly building blocks. They found that the Bacillus megaterium was found to be very effective in calcite deposition on the surface of ash bricks which leads to reduction in permeability, decrease in water absorption leading to enhanced durability. The strength of ash bricks can be significantly increased by the application of bacterial calcite. The process of bio calcification by bacteria can serve as an important tool to enhance the durability of civil structures constructed with ash bricks.

H.K. Kim (2013) et al, investigated that the characteristics of microbiological precipitation of calcium carbonate on normal and lightweight concrete by two types of bacteria, Sporosarcina pasteurii and Bacillus sphaericus. Concrete specimens were treated by pure water, a cell-free medium, and medium with cells; and a macrographic study of the distribution of calcium carbonate precipitation on the concrete specimens was carried out using a conventional digital camera to investigate the effects of the addition of bacteria. As a micrographic study, scanning electron microscope (SEM) images and energy dispersive spectroscopy (EDS) spectra were used to observe the shapes and distributions of the calcium carbonate crystals at a microscale level. The X-ray diffraction (XRD) analysis was carried out to characterize the crystalline phases of the calcium carbonate crystals formed in liquid medium with and without cells. In addition, a capillary water absorption test of the concrete specimens was conducted to evaluate the effects of microbiological precipitation of calcium carbonate on the properties of moisture transport, which may affect the durability of the concrete. They found that B. sphaericus precipitated denser calcium carbonate crystals than S. pasteurii. Moreover, the concrete specimens treated by the medium with B. sphaericus showed the lowest weight increases per unit area.

Rafat Siddique (2011) et al, presented an overview of bacteria, their types based on the classification has been studied. Even the effect of bacteria on various parameters in concrete proves to be beneficial development. Based on the studied properties like compressive strength, permeability, water absorption, chloride ingression, the microbial mineral precipitation appears to be a promising technique at this state of development. They found that the type of bacterial culture and medium composition had a profound impact on calcium carbonate crystal morphology. The use of pure culture resulted in a more pronounced effects. Metabolic activities of some specific microorganisms in concrete are responsible to improve the overall behavior of concrete. It has been hypothesized that almost all bacteria are capable of $CaCO_3$ production because precipitation occurs as a byproduct of common metabolic processes such as photosynthesis, sulfate reduction, and urea hydrolysis. Even the effect of bacteria on various parameters in concrete proves to be beneficial development and the compressive strength is sufficiently increased.

Sunil Pratap Reddy (2010) et al, proposed to use bacillus subtilis, which can produce calcite precipitates on suitable media supplemented with a calcium source. Cement mortar cubes with four different cell concentrations were cast and control specimen was also cast. This study showed a significant increase in the compressive strength was observed due to the addition of bacteria for a cell concentration of 10^5 cells per ml of mixing water. From Scanning Electron Micrography analysis, it is noted that pores were partially filled up by material growth with the addition of the bacteria. Reduction in pore due to such material growth will obviously increase the material strength. Based on their experimental investigation, they resulted that Bacillus subtilis can be produced from lab which is proved to be a safe and cost effective. The addition of bacillus subtilis bacteria improves the hydrated structure of cement mortar. The compressive strength of cement mortar is maximum with the addition of bacillus subtilis bacteria for a cell concentration of 10^5 cells per ml of mixing water. So, bacteria with a cell concentration of 10^5 cells per ml of mixing water was used in the investigation. Compressive strength is increased up to 14.92% at 28 days by addition of bacillus subtilis bacteria when compared to conventional concrete. The addition of bacillus subtilis bacteria showed significant improvement in the split tensile strength than the conventional concrete. From the durability studies, the percentage weight loss and percentage strength loss with 5% $H2SO_4$ revealed that Bacterial concrete has less weight and strength losses than the conventional concrete. Durability studies carried out in the investigation through acid attack test with 5% $H2SO_4$ revealed that bacterial concrete is more durable in terms of “Acid Durability Factor” than conventional concrete and bacterial concrete is less attacked in terms of “Acid Attack Factor” than conventional concrete. From the above they concluded that bacillus subtilis can be easily cultured and safely used in improving the performance characteristics of the concrete.

Navneet Chahal and Rafat Siddique (2008) purposed in this study that with use of Sporosarcina pasteurii which would make it, self-healing. The bacteria present in the concrete rapidly sealed freshly formed cracks through calcite production. The bacterial concentrations were optimized to 103, 105 and 107 cells/ml. In concrete mix, cement was replaced with fly ash, and silica fume. The percentage replacement of fly ash and silica fume was by weight of cement. The percentage use of fly ash was 0%, 10%, 20% and 30%, and that silica fume were 0%, 5% and 10%. The experiments were carried out to evaluate the effect of S. pasteurii on the compressive strength, water absorption, water porosity and rapid chloride permeability of concrete made with fly ash and silica fume up to the age 91 days. The test results indicated that inclusion of S. pasteurii enhanced the compressive strength, reduced the porosity and permeability of the concrete with fly ash and silica fume. The improvement in compressive strength was due to deposition on the bacteria cell surfaces within the pores which was scanned by electron microscopy and confirmed by XRD which revealed calcium carbonate precipitation. This precipitation reduced the chloride permeability in concrete with fly ash and silica fume. The bacteria improve the permeability of concrete by improving its pore structure and the Willem De Muynck et al, described in this paper the effects of bacterial carbonate precipitation (biodeposition) on the durability of mortar specimens with different porosity. Durability was assessed from the permeation properties and resistance towards degradation processes. The surface deposition of calcium carbonate crystals decreased the water absorption with 65 to 90% depending on the porosity of the specimens. As a consequence, the carbonation rate and chloride migration decreased by about 25–30% and 10–40% respectively. An increased resistance towards freezing and thawing was also noticed. The results obtained with the biodeposition treatment were similar as those obtained with conventional surface treatments. Based on study they demonstrated that the biodeposition treatment resulted in an increased resistance of mortar specimens towards carbonation, chloride penetration and freezing and thawing. In the case of cementitious materials, the biodeposition treatment might be regarded as a coating system, as the carbonate precipitation was mainly a surface phenomenon due to the limited penetration of the bacteria in the porous matrix.

V. Achal (2013) et al, studied that the role of bacteria Bacillus sp. on the durability properties and remediation of cracks in cementitious structures. ‘‘Biocement’’ induced by a Bacillus sp. lead to more than 50% reduction in the porosity of mortar specimens, while chloride Permeability of concrete changed from ‘‘moderate’’ to ‘‘very low’’ as indicated by rapid chloride permeability test. The bacteria successfully healed the simulated cracks of depths including 27.2 mm in cement mortars with increase in the compressive strength as high as 40% of that of control. The results clearly showed microbially induced calcium carbonate precipitation can be applied for various building materials for remediation of cracks and enhancement of durability. They demonstrated that the effectiveness of microbially induced calcium carbonate precipitation used to remediate cracks in building materials. The crack sealing process enhances the strength and durability of the building structures. It results in the decrease in water and chloride ion permeability. It also binds the sand particles together and acts like cement. This process can improve the present technologies that are toxic and susceptible to UV radiation. Moreover, the reported system has the potential to bring in self-healing ability in structures.

N. De Belie and W. De Muynck (2009) proposed to present in this paper that with the use of bacillus sphaericus to repair crack In order to explore the crack healing potential of a biodeposition treatment, standardised cracks of 0.3 mm were produced in concrete specimens by introducing thin copper plates in fresh concrete and removing them after 1 day, or by performing splitting tensile tests on concrete cores wrapped in fibre reinforced polymer sheets. The use of pure bacteria cultures as in the previously developed biodeposition procedure did not result in sufficient calcium carbonate precipitation to completely bridge the cracks. Therefore, the bacteria were protected in a silica sol, resulting in the formation of a bioceramic material which was able to bridge the cracks completely. The crack healing potential was illustrated by microscopic evaluation, ultrasound transmission measurements and low pressure water permeability tests. The treatment of cracks with the bacteria incorporated in the bioceramic material resulted in a large reduction of the water permeability. They show that crack repair can be obtained through biodeposition treatments in which a Bacillus sphaericus culture is incorporated in sol-gel. A calcium source such as $CaCl_2$ or $Ca(NO_3)_2$ should be provided. Visual examination and ultrasound transmission testing proved that complete sealing of artificial cracks of 0.3 mm wide and 10 mm deep could be obtained. With consideration of water tightness In relation to water tightness, again treatments with Bacillus sphaericus, bioceramic material and a calcium source appeared to be effective in healing real cracks of 0.01 to 0.6 mm. These repair materials were much more effective than application of sol-gel or bacteria only. They also reduced the concrete permeability much more than a cement grout repair technique and had a similar effect as epoxy injection.

S.Krishnapriya (2015) et al, purposed to use three type of bacteria named Bacillus megaterium BSKAU, Bacillus licheniformis BSKNAU *and* bacillus flexus BSKNAU, compared with Bacillus megaterium MTCC 1684, to isolate and identify calcite precipitating bacteria and to check the suitability of these bacteria for use in concrete to improve the strength. Cracks were induced in the beam specimens by introducing a thin copper plate of thickness 0.3 mm up to a depth of 10 mm in the fresh concrete. The plates were removed before final setting of concrete such that a crack was clearly visible in the beam specimens. The specimens were removed from moulds after 24 hours and cured in water. The mix design which was use is M25.They found that the Bacillus megaterium MTCC1684 exhibited high urease activity. The newly isolated bacterial strains were identified by 16S rRNA gene sequencing as Bacillus megaterium BSKAU, b*a*cillus licheniformis BSKNAU and Bacillus flexus BSKNAU. The urease activity, endospore formation and calcium carbonate precipitation of Bacillus megaterium BSKAU and Bacillus licheniformis BSKNAU is close to Bacillus megaterium MTCC 1684. The compressive strength of bacterial concrete specimens with Bacillus megaterium BSKAU, Bacillus licheniformis BSKNAU, Bacillus flexus BSKNAU and Bacillus megaterium MTCC 1684 has increased when compared to control concrete specimens. It can be concluded that Bacillus megaterium BSKAU, Bacillus licheniformis BSKNAU and Bacillus megaterium MTCC 1684 are suitable for use in concrete as they have resulted in increased strength and complete healing of cracks in concrete.

The author Farzaneh Nosouhian (2015) et al, evaluates microbial surface treatment in order to prevent sulphate ions penetration. Five groups of concrete specimens were cast and cured and were then surface treated applying three different microbial suspensions employing Sporosarcina pasteurii, Bacillus subtilis and Bacillus sphaericus bacteria. Durability was assessed through the mass losses, volume changes (expansion), water absorption and compressive strength. In order to consider further permeation properties, chloride penetration of biologically treated concrete was examined by a rapid chloride permeability test (RCPT). Experimental results and a durability loss index (DLI) indicated that biological surface treatment reduces concrete degradation in sulphate environments and improves durability characteristics. Also, the RCPT results confirmed that this technique limits chloride penetration into the concrete.Based on experimental results of the present study, with specific cell concentrations tested, they resulted that,Mass loss of the biologically surface treated specimens which are exposed to sulphate environment was observed to decrease.Expansion rate of the treated specimens exposed to sulphate environments was observed to be reduced due to the presence of bacterial precipitations which probably limited the sulphate ion penetration.Water absorption of concrete was found to be significantly reduced after applying biological surface treatment on concrete, which lower the water permeability.Bacterial treatment was observed to slightly increase the compressive strength of the concrete and also enhance the development of compressive strength. A durability loss index (DLI) for the concrete which was introduced in this paper demonstrated that surface treatment of concrete by S. sphaericus bacteria produced the most durable concrete in a sulphate environment amongst all the tested biological treatments and specific cell concentrations tested in this study.

Kim Van Tittelboom (2010) et al, purposed to describe Ureolytic bacteria such as Bacillus sphaericus are able to precipitate $CaCO_3$ in their micro-environment by conversion of urea into ammonium and carbonate. The bacterial degradation of urea locally increases the pH and promotes the microbial deposition of carbonate as calcium carbonate in a calcium rich environment. These precipitated crystals can thus fill the cracks. The crack healing potential of bacteria and traditional repair techniques are compared in this research by means of water permeability tests, ultrasound transmission measurements and visual examination. Thermogravimetric analysis showed that bacteria were able to precipitate $CaCO_3$ crystals inside the cracks. It was seen that pure bacteria cultures were not able to bridge the cracks. However, when bacteria were protected in silica gel, cracks were filled completely. In this research, they use silica gel to protect the bacteria against the high pH in concrete. Crack sealing by means of this biological treatment resulted in a decrease in water permeability. Crack treatment with B. sphaericus, immobilized in silica gel, resulted in an increase in ultrasonic pulse velocity, indicating that crack bridging was obtained. Visual examination of the cracks proved that this technique resulted in complete filling of the cracks.

Sudipta Majumdar (2012) et al, purposed that this investigation deals with the compressive and flexural strengths increment of a novel bacterial protein (bioremediase) incorporated pozzolana cement based mortar specimens. This protein also in-creases durability and crack repairing attributes that is more effective in pozzolana cement. Higher constituent percent-age of silicate in pozzolana cement leads to higher silica leaching activity within the matrix manifesting of higher strength and durability of the samples. Eco-friendliness and wide range temperature stability lead added advantage to the protein for potential additive in high performance concrete technology. This means in practice that a substantial part of the cement of the mortar/concrete mixtures can be left out while still obtaining needed final strength. This would substantially improve the ecological sustainability of mortar/concrete, as it is particularly cement that causes massive CO_2 emission what negatively affects the global climate. In this study they conclude that the increment of strengths and other essential features of mortar/concrete materials are substantially higher for pozzolana cement based mortar/concrete materials than ordinary Portland cement based specimens when ad-mixed to bioremediase protein.

Navneet Chahal (2012) et al, presents the results of an experimental investigation carried out to evaluate the influence of Sporoscarcina pasteurii bacteria on the compressive strength and rapid chloride permeability of concrete made without and with fly ash. Cement was replaced with three percentages (10, 20 and 30) with fly ash by weight. Three different cell concentration (0, 10^3,10^5,10^7cells/ml) of bacteria were used in making the concrete mixes. Tests were performed for compressive strength, water absorption and rapid chloride permeability at the age of 28 days. Test results indicated that inclusion of S. pasteurii in fly ash concrete enhanced the compressive strength, reduced the porosity and permeability of fly ash concrete. Maximum increase (22%) in compressive strength and four times reduction in water absorption was observed with 10^5 cells/ml of bacteria. This improvement in compressive strength was due to deposition on the bacteria cell surfaces within the pores. They conclude that Bacteria S. pasteurii plays a significant role in increasing the compressive strength of fly ash concrete by up to 22% at the age of 28 days. The increase in compressive strength is mainly due to consolidation of the pores inside the fly ash concrete cubes with bacterial induced calcium carbonate precipitation. S. pasteurii causes four times reduction in water absorption which could inturn increase durability of concrete structures. Bacterial calcite deposition observed nearly eight times reduction in chloride permeability; hence the shelf life of the concrete structures can be increased.

Varenyam Achal (2011) et al, investigated the effects of Bacillus megaterium ATCC 14581 on compressive strength, they use mortar and concrete specimen for compressive strength, water absorption test and water impermeability test. They found that with the increase of fly ash concentration in mortars, bacterial cell enhance compressive strength up to 19%. Compared to control specimens. The specimen which is treated with bacteria have absorb less water than controlled specimen. They specify that bacteria deposited on surface of concrete specimens resulted in decrease the permeability and water uptake than the controlled specimens. Scanning electron microscopy give the proof of calcite deposition in concrete specimens. They conclude that the use of fly ash is promisingly increase the scope of developing the economic, environmental friendly concrete.

III.CRITICAL REMARKS

1. Microbial activity is highly preferable because of it produce calcite which is free from pollution and favourable in environment condition.
2. With the addition of bacillus subtilis the percentage water requirement of concrete is reduced.
3. At cells concentration of 10^5 cells/ml of mixing water the maximum compressive strength is achieved in the case of bacillus subtilis.
4. In the case of durability the percentage strength loss and percentage weight loss with 4 to 5 % of $MgSO_4$ relieved that bacterial concrete has less strength loss and weight loss compared to normal concrete.
5. Water absorption was less in mixtures with bacterial addition as compared to the mixtures without bacteria.

6. It is found that the use of organic matter and the bacteria the overall strength and durability of concrete structure is improved.
7. With the use of bacillus subtilis in bacterial cell wall, the compressive strength is increase 15%.
8. With the use of bacteria large crack can be heal especially underground structure were repair is difficult.

IV.CONCLUSION

Based on study we conclude that,

- Bacteria are able to remediate crack at early stage with small to medium crack size.
- The flexural strength did not much improve with addition of bacteria. It require more time to heal the crack with bacteria.
- The *Bacillus subtilis* were isolated from soil and this bacteria are environment friendly which is proved to be safe.
- If microbiology laboratory is developed, the culture and growth of bacteria can be done at negligible cost. Hence it can be cost effective also.

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