Assessment on Strength of Self-healing Concrete by using Bacillus Pseudofirmus as Partial Replacement with Cement: A Review

Ankit Ghatiya[1] Dr. Umesh Pendharkar[2]
[1]P.G Student [2]Professor
[1,2]Ujjain Engineering College, Ujjain (M.P.)

Abstract— The purpose of this research is to investigate the nature of microorganism Bacillus Pseudofirmus for enhancement of self-healing property and strength in concrete. Cracks in concrete are integral and are one of the implicit weaknesses of concrete. Water and other salts percolate through these cracks, corrosion introduce, and thus reduces the life of concrete. So there was a need to develop an inherent self-healing material which can remediate the cracks and fissures in concrete. The concrete structures have various durability issues due to the different conditions and it results to irretrievable damage to the structure and eventually reduction in the strength of concrete structure. Therefore, for enhance the mechanical properties of concrete structures cement is replaced by Bacillus Pseudofirmus. For this purpose Bacillus Pseudofirmus is replaced by 0%, 2.5%, 5% by the weight of cement. Numerous tests were conducted like compressive strength, flexural strength, split tensile strength and stress-strain curve at the different percentage of Bacillus Pseudofirmus 2.5%, 5% for the time period of 7, 14, and 28 days curing and compare with conventional concrete.

Key words: Bacillus Pseudofirmus, Application, Mechanical Properties, Durability, Self-healing Concrete

I. INTRODUCTION

Bacterial concrete is a superior type of concrete it has the ability to repair itself separately. One another advantage of bacterial concrete is that the introduction of bacteria in concrete also helps in enhancing the mechanical as well as durability properties of concrete in both natural and laboratory conditions. Concrete which forms most important component in the construction Industry as it is cheap, easily available and convenient to cast. But drawback of these materials is it is weak in tension so, it cracks under sustained loading and due to aggressive environmental agents which ultimately reduce the life of the structure which are built using these materials. This method of damage take place in the early life of the building structure and also during its life time. Synthetic materials like epoxies are used for remediation. But, they are not compatible, costly, reduce aesthetic appearance and need constant maintenance. Bacteria made Calcium Carbonate (Calcite) precipitation has been anticipated as an alternative and environment friendly crack remediation and hence improvement of strength of building materials. Self-healing concrete could solve the problem of concrete structures deteriorating well before the end of their service life. Concrete is one of the key materials used in the construction, from the foundation of buildings to the structure of bridges and underground structures. Conventional concrete has a flaw, it tends to crack when subjected to tension. Because the other pre-defined materials for enhancement in strength and durability were not good for environment and also more costly than bacterial concrete and they also require regular maintenance. This study is to understand the significance of different micro-organisms in concrete.

Crack-penetrating water would not only dissolve calcite ($CaCO_3$) particles exist in mortar matrix, but would also react together with atmospheric carbon dioxide with not fully hydrated lime constituents such as calcium oxide and calcium hydroxide according to the following reactions:-

$$CaO + H_2O \rightarrow Ca(OH)_2$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

II. LITERATURE REVIEW

Ashwinkumar A. Kalaje, Prof. M. Manjunath Prof. Santosh A. Kadapure, [1], This paper presents the results of an experimental study carried out to evaluate the influence of Bacillus sphaericus bacteria on the compressive strength, split tensile strength, flexural strength, shear strength, water absorption and chloride permeability of concrete made without and with fly ash. Cement was replaced with two percentages (10 & 20) with fly ash by weight. Three different cell concentration of bacteria were used in making the concrete mixes. Tests were performed at the age of 28 days. Test results indicated that inclusion of B. sphaericus in fly ash concrete enhanced the compressive strength reduced the water absorption and chloride permeability of fly ash concrete. Maximum increase in compressive strength 15.47% was detected with 105cells/ml of bacteria. This improvement in strength was due to deposition on the bacteria cell surfaces within the pores. The present work highlights the impact of bacteria on the properties of concrete made with adding cementing material such as like fly ash. Usage of bacteria like B. sphaericus improves strength and durability of fly ash concrete through self-healing effect.

H.M. Jonkers & E. Schlangen, [2], In this paper the author has described about the action of bacteria after the insertion into the concrete. Viable bacteria as self-healing agent and the autonomous crack healing system of self-healing agent are the two main points that have been focused in this paper. As regular manual maintenance and repair of concrete constructions is costly and in some cases not at all possible, inclusion of an autonomous self-healing repair mechanism would be highly advantageous as it could both reduce maintenance and increase material durability.

Kartik M. Gajjar, [3], According to this research paper 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% $MgSO_4$, 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.

Tae-Ho Ahn and Toshiharu Kishi, [4], This study aims to develop and apply self-healing concrete as a new method for crack control and enhanced service life in concrete structure. This theory is one of the maintenance-free methods which, apart from saving direct costs for maintenance and repair, reduces the indirect costs – a saving generally welcomed by contractors. In this research, the self-healing phenomenon of autogenous healing concrete using geo-materials for practical industrial application was investigated. The results show that the crack of concrete was significantly self-healed up to 28 days re-curing. Crack-width of 0.15mm was self-healed after again curing for 3 days and the crack width decreased from 0.22 mm to 0.16 mm after again curing for 7 days. Furthermore, it was almost completely self-healed at 33 days. It was founded that this phenomenon occurred mainly due to the swelling effect, expansion effect and re-crystallization. In this study, the new method of self-healing design to repair cracks in cracked concrete was suggested, and the self-healing properties of cracked concrete using various mineral admixtures were investigated.

Mayur Shantilal Vekariya, Prof. Jayeshkumar Pitroda, [5], He 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 microbial 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. 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 suitable for usage. This method is desirable but it require more research study and the microorganism is require some good condition.

Z. P. Bhathena and Namrata Gadkar, [6], Natural processes and human activities can create fissures in concrete that tends to reduce the service life of the structures. A novel strategy to remediate such Natural processes and human activities can create fissures in concrete that structures is bio mineralization of calcium carbonate using microbes. when grown in nutrient media pH 8, supplemented with 2.5% urea along with enhancing its ability to initiate increase in biofilm production by 29.57% The shortlisted strains were also able to form calcium carbonate deposits as checked by FEG-SEM examination and different crystal structures such as spherical – smooth and rough, dumbbell shaped and plate-like were observed. An increase in compressive strengths of mortar as performed according to IS 4031:1988 was observed after 7 days of curing in water indicating that calcium carbonate precipitation helps in increasing the strength of cement. Thus, these isolates can be used within cement mix to increase the strength and maintain its durability.

Chintalapudi Karthik, Rama Mohan Rao. P, [7], The phenomenon formation of micro-cracks in concrete is common, this leads to costly maintenance. Concrete needs to be repaired. This causes degradation of concrete leads to ingress of deterious substances into concrete, results in deterioration of structures. To overcome these situations self-healing techniques are adopted. Bio mineralization techniques give favourable results in sealing the micro-cracks in concrete. The freshly formed micro-cracks can be sealed up by continuous hydration process in concrete. The ureolytic bacteria i.e., bacillus pasteurii which can produce urea is added along with the healing agent to seal the freshly formed micro-cracks by CaCo3 precipitation. For the improvement of pore structure in concrete the bacterial concentrations were optimized for better results. Increase of durability, compressive strength and reduction of permeability in concrete is attained. Ability to heal and seal the cracks in concrete was observed. Maintaining pH under favourable conditions, permeability of concrete, crack healing capacity of concrete was observed.

Mohit Goyal, P. Krishna Chaitanya, [8], The major problem the construction industry concurs with is the high preservation cost of the concrete. Various natural processes such as weathering, faults, land sinking, earthquake, changes in moisture and temperature, have the tendency to create cracks in concrete. Therefore, to counter these effects, it has become necessary to come up with ways which will not only help in counteracting but also in improving the quality of concrete. In the present experiment, Bacillus Pasteurii, which has the property of bio calcification and can secrete calcium carbonate as an extracellular product has been used to prepare M25 concrete. This product is found to be responsible for filling the pores and cracks internally making the structure more compact. Also, laboratory investigations were carried out to compare the different parameters of bacterial concrete with ordinary concrete and concrete in which cement was partially replaced with Fly Ash and GGBS.

C. Mohanasundharam, R. Jeevakkumar, K.Shankar, [9], Concrete is the most regularly used building material, the cracks in concrete create problem. Cracks in concrete occur due to various mechanisms such as - shrinkage, freeze-thaw reactions and mechanical compressive and tensile strength. Cracking of the concrete surface may improve the deterioration of embedded steel bars as ingression rate of corrosive chemicals such as water and chloride ions in to the concrete structure increased. Therefore a novel technique has been developed by using a selective microbial working process. One such thought has lead to the development of a very special concrete known as Bacterial Concrete where bacteria is induced in the mortars and concrete to heal up the faults. In this study, The properties of control concrete and bacterial concrete are studied by conducting various tests such as compressive strength, tensile strength, flexural test with varying grades of concrete M20, M25, M30.

Michelle M. Pelletier, Richard Brown, Arun Shukla and Arijit Bose, [10], They developed a concrete material exhibiting self-healing properties and corrosion inhibition. This system involves a sodium Bacillus Pseudofirmus solution stored in polyurethane microcapsules present in the concrete matrix. Compressive strength is unaffected by the

presence of capsules. Samples are strained to the point of initial failure in a three-point bend system, and retested after one week. The load at failure in the capsule-containing samples is 26% of the original value, while the samples without capsules displayed a recovery of 10%. The flexural strength recovery, the improved toughness and the attenuation of corrosion make it a promising material for construction. The results from the compressive strength tests show that the capsules do not interfere with the cementitious matrix. Their real ability is demonstrated in testing the flexural strength after inducing microcracks.

Dilja Rose Joseph, Life John, [11], Concrete is a main building material which is an essential component of infrastructure and buildings. Due to its brittle nature with low tolerance for strain, the chance for cracking is more. These cracks expose the steel reinforcement to the atmosphere, leading to corrosion which increases the maintenance costs and also losing the structural integrity over long periods of time. Self-healing concrete consists of a bacterium (Bacillus Subtilis) which heals the damage done and can also reduce the amount of damage sustained by the concrete structure. Fly ash continues the hydration after 28 days and also produces secondary C-S-H gel very slowly. So the hydrated products from fly ash modify the microstructure and seal the crack. An innovative approach of microbial calcite precipitation in fly ash concrete needs to be investigated. The fly ash microbial concrete is to be made by adding 105cells/ml Bacillus Subtilis bacteria solution concentration, at the fly ash concentrations of 10%, 20% and 30% of cement replacement. The study includes finding the optimum percentage of fly ash in microbial concrete containing Bacillus Subtilis JC3 to achieve the best strength properties.

Sudipta Majumdar1, Manas Sarkar Concrete, [12], widely used construction material suffers from cracks and low tensile strength that cut down the load capacity resulting in shortening of self-life. Biologically modified construction materials become more popular for higher strength and long-term sustainability. This investigation deals with the compressive and flexural strengths increment of a novel bacterial protein 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 footprint (sustainability) of mortar/concrete, as it is particularly cement that causes massive CO_2 emission what negatively affects the global climate (significantly contributes to global warming).

Etaveni Madhavi, Dr. Rahul Naik, [13], The objective of this research work is to reduce the cost of the construction. Now a days the industrial wastes are rapidly increasing more. To utilize such materials and reduce such type of waste in environment. The cement is replaced by the GGBS and fly ash with bacteria of 106 bacillus pasteurii in M40 mix. the GGBS and fly ash as taken in the proportions of 10% by weight of cement. From this research the results are much better as compare to the convention concrete.

Amudhavalli N. K., Keerthana K. , Ranjani A, [14], This paper explains about the overview of bacterial concrete There are many papers which discussed about the various strains of bacteria. Self-healing agents such as epoxy resins, bacteria, fibre are used to heal cracks in concrete. Among these, bacteria used in concrete are effective. When the bacteria is mixed with concrete the calcite precipitates forms and these precipitates filling the cracks and makes the crack free concrete. The state of art results in all projects show that material designed as self-healing agents.

Vijeth N Kashyap, Radhakrishna, [15], Crack is commonly observed failure in the case of concrete. Crack may develop due to addition of excess of water to during mixing of concrete, or may be due to shrinkage and creep. In the present study, crack healing and improvement of physical properties of cement paste, mortar and concrete are studied. It is done by the addition of bacterial strains namely Bacillus Sphaericus and Sporosarcina Pastuerii. It is found that these bacteria when added at 106 concentration of cells/ml of water to cement composites increased by about 39.8% and 33.07% in paste. There is an increment of 50% and 28.2% in mortar for two bacterial strains. The strength increase is found to be 18.3% and 12.2% for Bacillus Sphaericus and Sporosarcina Pastuerii respectively for concrete.

III. Methodology

The methodology of the investigation starts from the study on the properties of the different materials and the past work done from the collection of literatures for review. The bacterial properties of the bacillus pseudofirmus to be used need to be well studied.

Various types of bacteria used in concrete from literature review:

- Bacillus pasteurii
- Bacillus cereus
- Bacillus sphaericus
- Escherichia coli
- Bacillus subtilis etc.

IV. Conclusion

According to the previous researches, certain of the bacteria are not good for human health but some other bacteria like bacillus Sphaericus, bacillus pasteurii, bacillus subtilis, and bacillus flexus does not impose any bad effect on human health and also shows higher ability of calcite precipitation.

Based on study we determine that,

- Bacteria are able to heal 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.
- Cost of bacteria is more as compare to other ingredients.

Impact behaviour of nominal concrete mix (concrete with 0% bacillus pseudofirmus) to that of concrete mixes

incorporated with percentages like 2.5%, 5% by weight of cement) to find the strength of concrete. As it is a review paper, so final results and detailed work, graphs, curves, diagrams etc. will be discussed in final assessment paper.

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