Development of Self Healing Concrete to Improve Durability of Structures

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Abstract: **- Concrete is most commonly used construction material which is strong in compression and weak in tension. The major drawback of concrete is formation of cracks, which affects the serviceability of concrete. When the applied load exceeds the limit, cracks develops on the structure through which water, salts and other foreign matters enters into the concrete and leads to the failure of the structure. Bacterially induced $CaCO_3$ precipitation has been proposed as an environmental friendly technique which can remediate cracks in concrete. Metabolic activities of bacteria in concrete can improve overall performance of concrete. In this paper an attempt to study bacterial concrete, types and classification of bacteria, mechanism, merits, demerits and applications of bacterial concrete.**

Key words: **- Concrete, bacteria, concrete strength, durability, applications.**

I. INTRODUCTION

Concrete is strong, durable, locally available building material widely used for construction. Concrete is a composite building material composed primarily of cement, aggregate and water. Plain concrete posses two major drawback as a structural material. They behave in brittle fashion and possess a very low tensile strength. It possess a low modulus, limited ductility and little resistance to cracking. Micro cracks develops during its manufacture due to inherent volumetric and micro structural changes. Hence it is necessary to impart tensile resistance properties to concrete structural members to use it as a load bearing material. If the load applied on the concrete is more than their limit of resisting load, it causes the strength reduction of concrete by producing the cracks in concrete and the treatment of cracks is very expensive. The entry of moisture and harmful chemicals into the concrete through cracks can result in decrement of strength and life. These defect can be rectified by utilizing self healing technology which has high potential to repair cracks in concrete and enhance the durability of concrete structures with a reduction of demand for repair and maintenance. A new and advanced way of improving properties of concrete is through mineralization of bacterial isolates. Bacterial organisms have the ability to produce Calcium Carbonates through metabolic activity. Bacteria incorporated concrete have enhanced durability as cracks in concrete can be rectified through mineral precipitation ($CaCO_3$). Bacillus species are aerobic spore forming gram positive bacteria with specialized thick walled dormant cells, viable for more than 200 years under dry condition. Incorporation of calcite precipitating bacteria to concrete in certain concentrations so that the bacteria will precipitate calcium carbonate when it comes in contact with water and this precipitate will heal the cracks. Bacterial concrete is also known as self - healing concrete or Bio concrete. Micro biologically induced calcite precipitation can heal cracks and improve the performance of the concrete.

II. LITERATURE REVIEW

Chithra P Bai et al.,(2016) ***"An experimental investigation on the strength properties of fly ash based bacterial concrete",*****[1]** This paper deals with the influence of Bacillus Subtilis bacteria on strength properties of fly ash concrete. In fly ash concrete, cement was partially replaced with 10%, 20% and 30% with fly ash by weight and optimizes the percentage of fly ash for making bacterial concrete. The bacteria Bacillus Subtilis of different cell concentrations 10^3, 10^5 and 10^7 cells/ml were used for making bacterial concrete. The experimental investigations were carried out for 28 and 56 days. Tests conducted include Compressive strength, Split tensile strength, Flexural strength and Ultrasonic Pulse Velocity. In fly ash concrete, maximum strength properties observed for 10% replacement of cement with fly ash and the percentage of fly ash is fixed as 10% for making bacterial concrete. In bacterial concrete, maximum strength properties obtained for the bacteria cell concentration of 10^5cells/ml.

K. Nagajyothi et al.,(2017) ***"Experimental study o n bacterial rice husk ash concrete by incorporating quarry dust as parti al replacement of fine aggregate",*****[2]** In this study, bacillus subtilis was used as a microbial material for the preparation of bacterial concrete. Control concrete was prepared for comparison with bacterial concrete. Rice husk ash (RHA) and Quarry dust (QD) are used as a partial replacement of cement and fine aggregate in both control concrete and bacterial concrete. Cement was partially replaced with 5%, 10%, 15% RHA and fine aggregate was replaced with 45% QD. Bacillus subtilis was added in the amount of 10^5 cells/ml during the mixing of bacterial concrete. Tests were performed to determine the compressive strength, split tensile strength and flexural strength for 3,7 and 28 days. It is observed that bacterial concrete increased the compressive, tensile and flexural strength of concrete, thus it was conclude that produced calcium carbonate has filled up some internal voids present in the concrete.

Nafise Hosseini Balam et al.,(2017) ***"Effects of bacterial remediation on compressive strength, water absorption, and chloride permeability of lightweight aggregate concrete",*****[3]** This paper presents an experimental investigation carried out to evaluate the influence of Sporosarcina pasteurii at cell concentrations of 10^6 cells/ml on water absorption, water permeability, compressive strength, and rapid chloride permeability of Light weight aggregate concrete(LWAC). Leca aggregates were left to soak in a solution of urea-$CaCl_2$ containing bacteria for 6 days to investigate biological improvement of aggregate quality. Four types of LWAC were made under the three treatments of bacterially-treated aggregates, bacteria inoculated in the concrete mix water, and both techniques employed simultaneously and with no bacteria used in either the aggregate or the concrete mix solution as the control. The results revealed an average reduction of about 10% in water absorption, 20% increase in compressive strength, and 20% reduction in chloride penetration in the experimental specimens relative to the same properties in the control ones.

Navneet Chahal et al.,(2013) ***"Permeation properties of concrete made with fly ash and silica fume: Influence of ureolytic bacteria*****",[4]**The paper presents the permeation properties of concrete made with fly ash and silica fume by adding ureolytic bacteria. The study involves the isolation of urease producing bacteria from alkaline soil. The bacteria were identified by the ability to sustain itself in alkaline environment of cement/concrete. The bacterial isolate was analyzed through DNA sequencing and the bacteria was identified as Sporosarcina pasteurii, which showed maximum urease production when it was grown on urease agar and broth. The bacteria present in the concrete rapidly sealed freshly formed cracks through calcite production. The bacterial concentrations were optimized to 10^3, 10^5 and 10^7 cells/ml. 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.

Pradeep Kumar.A et al.,(2015) ***"An Experimental Work on Concrete by Adding Bacillus Subtilis ",*** **[5]** This paper studies the performance of the concrete by the microbiologically induced special growth. Bacillus subtilis strain no jc3 was used for the study. The study showed significant increase in the compressive strength due to the addition of bacteria. When 30 ml of "Bacillus Subtilis" is added in M20 grade concrete it attains maximum compressive strength. In concrete self-healing property is successfully achieved due to addition of bacteria. It shows that the M20 grade bacterial concrete having higher compressive strength then the normal M25grade concrete and the self-healing property is successfully achieved in bacterial concrete.

R. Sri Bhavana et al.,(2017) ***"Experimental study on bacterial concrete with partial replacement of cement by fly ash",*****[6]** In this study, a biological repair technique was used in which bacteria of 10^5 cells/ml were mixed with concrete to heal the cracks. The experiments were carried out to evaluate the effect of Bacillus subtilis on the Compressive strength, Tensile strength and Flexural test for 3, 7 and 28 days. In addition to above technique fly ash was partially added in the place of cement. The fly ash (0, 10 and 30%) was added by weight of cement in concrete mix and experiments were carried out. The experimental results show that 10 % fly ash replaced concrete with and without bacteria has more strength when compared to the conventional concrete.

III. CLASSIFICATION OF BACTERIA

Bacteria are relatively simple, single celled organisms.

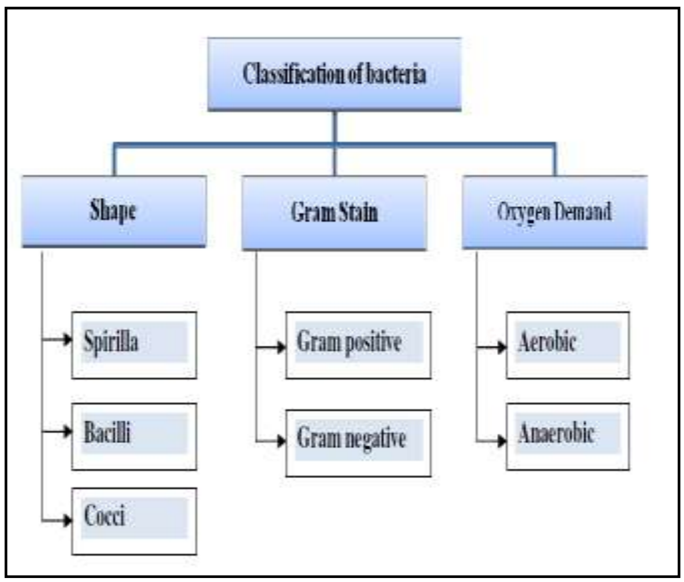

Fig.1. Classification of Bacteria

Various types of Bacteria used in concrete are:

- Bacillus pasteurii
- Bacillnes phaericus
- Escherichia colli
- Bacillus Subtilis

- Bacillus cohnii
- Bacillus pseodofirrius
- Bacillus balodurais

IV. MECHANISM

Microorganisms (cell surface charge is negative) draw cations including Ca^{2+} from the environment to deposit on the cell surface. The bacteria can thus act as nucleation site which facilitates for the precipitation of calcite which eventually plug the pores and cracks in concrete. The process of microbiologically induced calcium carbonate precipitation is having a complex biochemical re actions.

This following equations summarize the whole process:

$$Ca^{2+} + Cell \longrightarrow Cell\text{-}Ca^{2+}$$

$$Cell\text{-}Ca^{2+} + CO_3^{2-} \longrightarrow Cell\text{- }CaCO_3 \downarrow$$

Calcium carbonate precipitation depends upon calcium concentration, The concentration of dissolved inorganic carbon and pH.

V. ADVANTAGES

- *Enhancement of Compressive and Flexural Strength*

Compressive strength test results are used to determine that the concrete mixture as delivered meets the requirements of job specification. So effect of microbial concrete on compressive strength and flexural strength of concrete and mortar enhanced by the application of bacteria.

- *Better resistance towards Freeze thaw attack*

Application of microbial calcite may help in resistance towards freeze thaw reduction due to bacterial chemical process and also it reduces permeability thereby freezing process is decreased.

- *Self Repairing cracks without any external aid*

A concrete specimen gets filled with bacteria, nutrients and sand. Significant increase in compressive strength and stiffness values as compared to those without cells.

- *Reduction in corrosion of reinforcement.*

Application of microbial calcite may help in sealing the path of ingress chemicals and improve the life of reinforced concrete structures.

- Aesthetic appearance are not harmed
- Applicable to existing buildings in form of spray
- Decreased production of concrete
- Reduction in permeability of concrete
- It increases the durability of concrete
- It is pollution free, eco-friendly and natural
- Lower repair & maintenance cost
- Curbed carbon dioxide emission from concrete production.

VI. DISADVANTAGES

- Cost of bacterial concrete is higher
- Non-availability of IS codes

As it is a new research material no code is provided to use it. It is difficult to estimate the doses of bacteria to be used in concrete to get the optimum performance

- The clay pellets holding the self-healing agent comprise 20% of the volume of concrete.
- Growth of bacteria is not good in any atmosphere and media

Different types of nutrients and metabolic products used for growing calcifying microorganisms, as they influence survival, growth, biofilm and crystal formation. Numerous work should be done on retention of nutrients and metabolic products in the building material.

- Investigation process is of higher cost

Different types of bacteria have different properties to produce an amount calcite precipitation to identify this amount investigation of bacteria is done using "Scanning by Electron Microscopy" and this method is costly and require good skill to carry out this test.

VII. APPLICATIONS

The use of bacterial concrete has become

increasingly popular. It is used for

- Repairing of monuments constructed in limestone.
- Healing of concrete cracks
- Used for construction of

  -low cost durable roads

  -high strength building

  -river banks

  -low cost durable housing

- Enhancement in durability of cementious materials to improvement in sand properties.

VIII. CONCLUSION

The paper discusses that bacterial concrete is effective in improving strength and durability of concrete. Bacterial concrete exhibited higher compressive and tensile strength and lower porosity, acid attack, chloride penetration than that of the conventional concrete. Among the different bacteria that can be used for concrete, spores forming gram positive bacteria was found to give better results. Microbial concrete technology has proved to be better than many conventional technologies because of its eco friendly nature, self healing capacity and increase in strength and durability of concrete.

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