Experimental Study on Structural Behaviour of Self Healing Concrete using Bacillus Subtilis

Mr.R.Ramasamy[1], Mrs.M.Saranya[2]
[1]Dept of Structural Engineering
[2]AP, Dept of Civil Engineering
[1, 2] NSN College of Engineering and Technology, Karur.

Abstract- *Infrastructure cover a very board spectrum of different materials.This paper focuses on civil engineering structures, concrete and asphalt in particular. The public demand for such infrastructure is high level of service and performance, high durability and minimum negative ecological impact. New emerging self-healing material science provide solution to the problem. An overview is given of new development obtained in research on selfhealing of cracks in cement based material and asphalt concrete.*

I. INTRODUCTION

The Self-healing Concrete is one that senses its crack formation and reacts to cure itself without human intervention. Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specially selected types of the bacteria Bacillus subtilis, is added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200years.

Bacterial Concrete

The "Bacterial Concrete" can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. Bacillus subtilisis a soil bacterium, can continuously precipitate a new highly impermeable calcite layer over the surface of an already existing concrete layer. The favorable conditions do not directly exist in a concrete but have to be created. A Main part of the research will focus on this topic. Tests are conducted to study the mechanical properties of the above concrete with various percentages of Bacteria. The tests carried out are compressive strength test, split tensile strength test.

II. MECHANISM

Some possible mechanisms for Self-healing are:

- Formation of material like calcite.
- Blocking of the path by sedimentation of particles.
- Continued hydration of cement particles.
- Swelling of the surrounding cement matrix.

Objects of Biological Approach

To develop methods to enhance durability of concrete by adding bacteria. To regain the maximum strength of concrete after cracking rectification. To develop methods of concrete after cracking rectification.

BIO-MINERALIZATION

Natural processes such as weathering, faults, land subsidence, earthquakes and human activities create fractures and fissures in concrete structures and historical stone monuments. These fractures and fissures are detrimental since they can reduce the service life of the structure. In the case of 20 monuments and buildings of historic importance, these cracks tend to disfigure and destroy the structure. Use of bacterial concrete for remediating these structures will reduce the crack width and increase the strength of the structure. Therefore, a novel technique for remediating damaged structural formations has been developed by employing a selective microbial plugging process, in which microbial metabolic activities promote calcium carbonate (calcite) precipitation

The technique is called "Microbiologically Enhanced Crack Remediation (MECR). This technique comes under a broader category of science called "Bio- mineralization". It is a process by which living organism form inorganic solids. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas. This bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surface. The type of bacterial culture and medium composition had a profound impact on $CaCo_3$ crystal morphology

Microbial Concrete as Concrete Crack Remediation/Healing :

When cracks appear in the concrete, the possibility for corrosion of the embedded steel arises which could eventually ruin the integrity of the structure. Without immediate attention, the cracks can expand and cause extensive damage. Current forms of concrete crack remediation are structural epoxy, resins, epoxy mortar, and other synthetic filler agents. These synthetic solutions often need to be applied more than once as the cracks expand.

Clearly there is a need for an effective, long-term, environmentally safe method to repair cracks in concrete structures. Several research groups have investigated the possibility of bio-mineralization as an effective method to remediate cracks and fissures in concrete structures. Cracks filled with a mixture of B.subtilis, and sand showed a significant increase in compressive strength and stiffness, compared to cracks without cells. Microscopy confirmed the presence of calcite crystals and cells near the surface of the cracks.

PROCESS OF MANUFACTURE OF CONCRETE:

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad concrete. Therefore, it is necessary for us to know what the good rules are to be followed in each stage of manufacture of concrete for producing good quality concrete. The various stages of manufacture of concrete are:

- Batching
- Mixing
- Placing
- Compacting
- Curing

III. MATERIALS REQUIRED FOR EXPERIMENTAL STUDY

The ordinary concrete used in the test program consisted of cementing materials, mineral aggregates and corrosion inhibitor with the following specifications:

- Ordinary Portland Cement
- Fly ash
- Graded fine aggregates
- Graded coarse aggregates
- Water
- Chemical admixture
- Bacteria – Bacillus Subs tills
- Calcium lactate
- Urea Cacl2

Mixing of Bacteria

Luria Berta-powder form (6.75gms) + 500ml of distilled water peptone (3gms) + yeast extract (1.5gms) + Beef extract (1.5gms) + sodium chloride (3gms/100ml) + 1 Loop of Bacteria (gel medium) = Incubator 37^{o}C

Ability of Bacterial Concrete to Repair the Cracks:

Both attentions will be given on closure of cracks (blocking the path for ingress of water and ions)and on regaining mechanical properties. Cracks in concrete specimen subjected to various loading situations will be investigated before and after the healing. For this impregnation techniques and SEM will be applied. (Scanning electron microscope). On the other hand, the micro- organisms such as bacteria, cyono bacteria, algae, lichens, yeasts, fungi and mosses etc. Which are omnipresent and omnipotent are responsible for metabolism action that results in a microbial deposition of a protective $CaCO_3$ layer. Also, this process results in re-establishment of the cohesion b\n particles of mineral building materials and protects against further decay of stone material. To prove the positive effects of microbial $CaCO_3$ precipitation. The increase in porosity in concrete leads to increase in capillary water uptake, increase in gas permeability along with higher carbonation rate, high chloride migration and freeze-thaw damage.

Processing of Bacteria:

Concrete could soon be healing its own hairline cracking. Holes and pores of wet concrete are healed. Combined calcium with oxygen and carbon did oxide to form calcite is essential for healing tiny cracks which arrest the seepage of water.

IV. TEST RESULTS

Concrete plays a major role in the construction industry. For a durable structure, good quality concrete must be used. A Self-Healing Concrete for the future which says a common soil bacterium was used to induce calcite precipitation which is highly desirable because the mineral precipitation induced because of microbial activities is pollution free and natural. The workability test of the bacterial concrete resulted in 90mm of slump value.

We have found out that the compressive strength of the bacterial concrete with 5% bacteria + 0.005 mol/lit. Calcium lactate + Urea $CaCl_2$ is maximum in comparison of other compositions

Bacteria are added with the following:

1. Urea $CaCl_2$
2. Buffer -solution (phosphate buffer)

Bacteria will not survive in water. So, it cannot be mixed with water, and it was found out in the Research that the bacteria mixed with Buffer - solution give better results. Even it will not change the pH value when added with acid (or) alkali is added to it. The bacteria will be mixed in different ratios in the specimen concretes for testing and Research. The cost of bacterial concrete when compared to conventional concrete is more or less the same which will not require any rehabilitation work which is costlier for rectification of cracks after 15 years, but this self-healing concrete will help in regaining strength and healing of cracks automatically without any human intervention.

COMPRESSIVE STRENGTH TEST

Type of Concrete	**Compressive strength of concrete after 7 days**		
	Sampe 1	**Sample 2**	**Sample 3**
Conventional	22.7	23.0	23.5
5% Bacillus sp (B.sp)	24.0	24.5	24.8
5% B.sp+ 0.005 CL mol/l	25.7	26.3	26.5
5% B.sp+ 0.005 CL mol/l+ Urea $CaCl_2$	28	28.5	29.4

Compressive Strength of Concrete After 7 Days

Type of Concrete	**Compressive strength of concrete after 14 days**		
	Sampe 1	**Sample 2**	**Sample 3**
Conventional	28.3	29.03	29.5
5% Bacillus sp (B.sp)	29.1	29.9	30.3
5% B.sp+ 0.005 CL mol/l	31.0	30.8	31.9
5% B.sp+ 0.005 CL mol/l+ Urea $CaCl_2$	32.5	32.0	33.3

Compressive Strength of Concrete After 14 Days

Type of Concrete	**Compressive strength of concrete after 28 days**		
	Sampe 1	**Sample 2**	**Sample 3**
Conventional	31.7	32.5	32.9
5% Bacillus sp (B.sp)	33.2	34.5	34.9
5% B.sp+ 0.005 CL mol/l	34.5	35.8	37.0
5% B.sp+ 0.005 CL mol/l+ Urea $CaCl_2$	35.4	36.5	37.5

Compressive Strength of Concrete After 28 Days

SPLIT TENSILE STRENGTH TEST

The split tensile strength of the cylinder was calculated as per IS 5816:1999. For tensile strength test, the dimensions of specimens were 150 mm diameter and 300 mm length was casted. In this test three cylinders were tested and their average value was reported. The split tension test was conducted by using digital compression machine having 2000 KN capacity.

Split tensile strength was calculated by using following formula: Spilt Tensile strength (N/mm^2) = $2P / \pi DL$ Where,

P = Failure Load (KN)
D = Diameter of Specimen (mm) L = Length of Specimen (mm)

Test results of split tensile strength for M1, M2 and M3 are listed in table below.

Si.No.	**Concrete Mix**	**Split Tensile Strength at Initial Crack Load (N/mm^2)**					
		7 Days	**Strength after 12 Days**	**14 Days**	**Strength after 12 Days**	**28 Days**	**Strength after 12 Days**
1	**M1**	**2.35**	**1.67**	**3.10**	**2.30**	**3.97**	**3.16**
2	**M2**	**2.14**	**1.95**	**3.35**	**2.92**	**4.14**	**3.70**
3	**M3**	**2.10**	**1.92**	**3.15**	**2.95**	**3.85**	**3.70**

FLEXURAL TEST

The beam was exposed to two points loading to expose the be heavier of the RCC beam. As the load increases the crack width is also improved and prolonged towards the top of the beam. The mode of failure of RCC beam was flexure which is due to yielding of steel in tension zone. The concrete was crushed and spelling down. Fig. 4 represents the failure pattern of RCC beam.

Energy Absorption Capacity of Beams

The cumulative energy absorption capacity of RCC and SHC beams are plotted as in the Chart -4 shows below. The Self-Healing Concrete beams shows higher Energy absorption value when compared to RCC beams.

V. CONCLUSION

The following conclusions are arrived from the conducted experimental study and the results are indicated as follows.

- When the Bacterial concentration increases the Calcite precipitation increases.
- The load carrying capacity of conventional beam and Self- healing concrete beam were found as 88 KN and 92 KN respectively.

The deflection of Conventional beam and SHC beams were found as 7.75 mm and 10.1 mm for the ultimate load.

- The energy absorption capacity of SHC beams was found as 481.76 KN- mm which is 30% greater than that of RCC beams.
- The stiffness factor of SHC beam was 21.70% lesser than Convention albums. The ductility factor for SHC beams was 4.24 where as for conventional beam was3.82.
- The ingress of liquids and ions that start reinforcement corrosion can be stopped and thus durability of the structure is enhanced.

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