CHAPTER 7
Self Healing Concrete using Geopolymer

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ABSTRACT

Waste management is emerging as one of the most troublesome and critical problems of the upcoming decades. Therefore, the utilization of industrial by-products as building materials components has been widely studied in recent years. Geopolymer concrete, with binder entirely substituted by slag or fly ash, is one of the materials, which combines positive environmental impact with satisfying mechanical parameters. Although various properties of geopolymers have been examined, the autogeneous self-healing potential of this alternative binder has not been thoroughly verified yet. This paper aims to validate whether geopolymer concrete made of alkali activated slag is capable of self-repair. Four different mortar mixes with two types of slag and varying activation parameters were investigated. The polyvinyl alcohol (PVA) fibers were added in order to control the crack width. The 1.2 × 1.2 × 6 cm beams were pre-cracked with the use of three point bending test at 7 days after casting to achieve crack opening of approximately 300 µm. The effects of various exposure conditions on the healing process were examined, i.e., lime water, different sodium silicate solutions and water. The self-healing efficiency as well as the evolution of the crack recovery was assessed by the observation of the crack surface with the use of digital optical microscope. The healed area of the crack was calculated and compared for all the specimens by applying the image processing techniques. The morphology of the healing products as well as their chemical composition were examined with the use of Scanning Electron Microscope with Energy Dispersive Spectroscopy.

Keywords: *Waste management, activation parameters, geopolymers, concrete etc.*

INTRODUCTION

Concrete is the most used product in the world next to water. But the major problem faced in the concrete structures is development of cracks. Cracking in the surface layer of the concrete will reduce the durability. Cracks in concrete are a common phenomenon due to the relatively low

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tensile strength. Durability of concrete Is impaired by these cracks since they provide an easy path for the transportation of liquid and gasses that potentially contain harmful substances. If micro-cracks grow and reach the reinforcement, not only the concrete itself may be attacked, but also the reinforcement will be corroded. Therefore, it is important to control the crack width and to heal the cracks as soon as possible. Self- healing of cracks in concrete would contribute to a longer service life of concrete structures and would make the material not only more durable but also more sustainable.

AIM AND SCOPE OF THE PROJECT

- To heal the premature cracks developed in concrete structures using bio- chemical materials.
- To repair the cracks develop on the surface of the concrete.
- To increase the durability and sustainability of the concrete structures.
- To reduce the corrosion in reinforced concrete structures.

OBJECTIVES:

- To determine the crack width developed in the concrete structures.
- To determine the self healing mechanism by providing various healing agent to reduce the crack width.
- To carry the SEM analysis to find the presence of materials in concrete elements.

CRACKS IN CONCRETE

The type of cracking provides useful information to help understand a crack's effects on structural stability. A crack's status is important. Active cracks may require more complex repair procedures that may include eliminating the actual cause of the cracking in order to ensure a successful long- term repair. Failure to address the underlying cause may result in the crack's repair being short -term, making it necessary to go through the same process again. Dormant cracks are those not threatening a structure s stability, but those responsible tor the structure must address durability issues and take appropriate action if aesthetis are a priority.

REASON FOR CRACKING

- Drying shrinkage crack
- Crack due to thermal stresses
- Crack due to chemical reaction
- Weathering cracks
- Corrosion of reinforcement

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- Poor construction practices
- Construction overloads
- Errors in design in detailing

TYPES OF CRACKS IN CONCRETE

- Shrinkage
- Hairline
- Settlement
- Temperature and shrinkage
- Vertical
- Diagonal
- Horizontal
- Structural
- Floor

TRADITIONAL METHOD OF CRACK REPAIRING EPOXY INJECTION

Epoxy injection method is used for cracks as narrow as 0.002 inch (0.05 mm). The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces and injecting the epoxy under pressure.

ROUTING AND SEALING OF CRACKS

Routing and sealing of cracks can be used in condition requiring remedial repair and where structural repair is not necessary.

CONCRETE CRACK REPAIR BY STITCHING

Stitching involves drilling holes on both sides of crack and grouting in U-shaped metal units with short legs. Stitching may be used when tensile strength must be reestablished across major cracks.

ADDITIONAL REINFORCEMENT FOR CRACK REPAIR

Cracked reinforced concrete bridge girders have been successfully repaired by inserting reinforcing bars and bonding them in place with epoxy.

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DRILLING AND PLUGGING METHOD

Drilling and plugging a crack consist of drilling down the length of the crack and grouting it to form a key. This method is most often used to repair vertical crack in retaining wall.

GRAVITY FILLING METHOD

Low viscosity monomers and resins can be used to seal cracks with surtace width of 0.001 to 0.08 in. high-molecular-weight methacrylates urethanes, and some low viscosity epoxies have been used successfully.

GROUTING METHOD IN CRACK REPAIR

Wide cracks, particularly in gravity dams and thick concrete walls, may be repaired by filling with Portland cement grout.

OVERLAY AND SURFACE TREATMENT OF CRACK

Fine surface cracks in structural slabs and pavements may be repaired using either bounded overlay of surface treatment if there will not be further significant movement across the cracks.

ROLE OF SELF HEALING CONCRETRE

Self- healing concrete biologically produce calcium carbonate crystals to seal the cracks appear on the surface of the concrete structures. Specific spore forming various species supplied with a calcium-based nutrient are incorporated in to the concrete suspended in mixing water. This bacterium based self healing agent is believed to remain hibernated within the concrete for years. When cracks appears in a concrete structures and water starts to seep in through, the spores of the bacteria starts microbial activities on contact with the water and the oxygen. In the process of precipitating calcite crystals through nitrogen cycle the soluble nutrients are converted to insoluble CACO3. The CACO3 solidifies on the cracked surface, thereby sealing it up. The consumption of oxygen, during the metabolic biochemical reactions to form CACO3 helps in arresting corrosion of steel because

the oxygen is responsible to initiate the process of corrosion thereby increasing the durability of steel reinforced concrete structures.

ADVANTAGES

- Remediates cracks quickly.
- Improve the compressive strength of concrete.
- Better resistance towards freeze and thaw attack.
- Reduce corrosion in reinforcement.
- Reduce permeability and increase durability.

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- Pollution free and eco-friendly.
- Lower repair and maintenance cost.

DISADVANTAGES

- Cost of bacterial concrete is high.
- Growth of bacteria is not good in any atmosphere and media.
- Non-availability of IS codes.
- Investigation process is higher cost.
- Bacteria used may not be good for human health.
- Requires skilled labour.

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.

METHODOLOGY

In order to achieve the objective the project has been divided into nine parts

- Literature survey
- Collection of material
- Sample preparation
- Material testing

- Casting of specimen
- Curing process
- Experimental investigation
- Comparison of result
- Conclusion

LITERATURE SURVEY

The literatures were collected from the various sources to provide the information about the self-healing concrete.

COLLECTION OF MATERIALS

To attain these goals, materials were collected from various sources. Material collection is the basic and important step in any project. Yet, the material that is used in a project should not cause any damage to the environment

SAMPLE PREPARATION

For the self-healing concrete the samples are prepared in various process. The samples are microorganisms, chemicals for healing agent, after preparation of samples the survival test to be conducted for bacteria to check the amount of production of calcium carbonate.

MATERIAL TESTING

Materials used for the self-healing concrete is based upon the efficient usage of their properties. The material is tested for cement, coarse aggregate, and fine aggregate. For cement initial setting time and specific gravity is tested. For coarse and fine aggregate specific gravity, fineness, size of aggregate, zone is tested of the material properties as per Indian standard code provisions.

CASTING OF SPECIMENS

Cube and beam specimens are casted for self-healing concrete. The mix proportion is M20 as per 1S 10262-2009. The reinforced beam and prism are casted for the work, the steel mould and wooden mould is used for casting.

CURING PROCESS

Alter specimen casting the curing process for specimens are follows. The casted specimens are demoulded after 24 hours. The curing process for specimen is fully immersed in water up to 28 days. The hydration process will happens when the specimen is immersed in water for curing processs.

EXPERIMENTAL INVESTIGATION

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The flexural strength is tested for the conventional and self-healing specimen. For the experimental setup for beam under universal testing machine. The specimen's are tested as per ASTM (American standard testing machine) andIS (Indian standard code). For prism the specimen testing is adapted from ASTMC348-97. The beam specimen is adapted from IS 516-1979.

COMPARISON OF RESULTS

The results from flexure strength prism and beam specimen were compared with before and after healing process. The results from the behavior of self healing specimen are achieved.

From the finishing of above steps and the results compares the conclusion will be drawn for the present study

LITARATURE REVIEW

GENERAL

The present investigation deals with studies on strength parameters of self- healing concrete and so attempt has been made to review briefly the available literatures was listed. A large number of investigations are available in the literature on the above topies and only those investigations related to flexure test and their parameters are discussed here.

REVIEW OF LITERATURRE

Emily N. Herbert and Victor C. Li (2010) investigated aboutSelf-Healing of Micro cracks in Engineered Cementitious Composites (ECC) Under a NaturalEnvironment. This paper builds on previous self-healing engineered cementitious composites (ECC) research by allowing ECC to heal outdoors, in the naturalenvironment, under random and sometimes extreme environmental conditions.Development of an ECC material that can heal itself in the natural environmentcould lower infrastructure maintenance costs and alloW for more sustainable development in the future by increasing service life and decreasing the amount ofresources and energy needed for repairs. Determining to what extent current ECC self-heal in the natural environment is the first step in the development of an ECC that can completely heal itself when exposed to everyday environmental conditions. This study monitored outdoor ECC specimens for one year using resonant frequency (RF) and mechanical reloading to determine the rate and extent of self-healing in the natural environment. It was found that the level of stiffness, and first cracking strength recovery increased as the duration of natural environment exposure increased. For specimens that underwent multiple damage cycles, it was found that the level of recovery was highly dependent on the average temperature and amount of precipitation between each damage event. However RE, stiffness, and first cracking strength recovery data for specimens that underwent multiple loading cycles suggest that self-healing functionality can be maintained under multiple damage events.

RaktipongSahamitmongkol (2012) discussed about Self-Crack Closing Ability of Mortar with Different Additives, In this Self-crack closing ability of cementitious materials Studied in various aspects. This research thus aims to investigate the effect of additives on this self-crack closing ability by observing and measuring crack width on the mortar specimens. Cracks were created on mortar specimens by splitting method at the age of 3 and 28 days. As most reports show that the best self-crack closing performance was achieved when a plenty of water was supplied, the cracked specimens were thus cured in water for investigation of the self-crack

sing ability Eight samples of each mix proportion were prepared. T hey were divided into two sets. Four of them were cracked at the age of 3 days while the others were cracked at the age of 28 days. Before creating cracks, those samples were sealed to prevent loss of moisture. The results indicate that adding some types of additive improved the self-crack closing ability of mortar. For the range of0 -

0.05 mm crack width, mortar with crystalline admixture showed the best performance to close its cracks at both cracking ages (3 and 28 days). For larger cracks, mortar with silica fume was more outstanding in terms of self-crack closing ability. Flyash was found to be the worst additive to promote selfcrack closing ability of mortar. All types of mortars show their self-healing performance to some extent. Each additive in each mortar has its own preferable conditions (mortar age at cracking and crack width) for performing its best self-crack closing ability.

Michelle M. Pelletier, Richard Brown developed a concrete material exhibiting self-healing properties and corrosion inhibition. This system involves a sodium silicate solution stored in polyurethane microcapsules present in the concrete matrix. The sodium silicate, released when the capsules are ruptured by propagating cracks, reacts with the calcium hydroxide in cement and produces a C- S-H gel that partially heals the cracks. Samples are stressed to the point of incipient 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. Sample Preparation4.202mL of Span 85 and 2.116mL of polyethylene glycol (PEG) were dissolved in 90mL of toluene. A 15mL aliquot was taken from this solution and placed into a separate beaker (referred to as E1). 0.682ml of methylene diiosocyanate (Basonat) and 0.0469mL of dibutyl tin dilaureate was dissolved in EI. This blend was mixed at 350 rpm to ensure a homogenous mixture and set aside. The original mixture (Span 85, PEG and toluene) was combined with 30ml of water, stirring at 8000rpm in a homogenizer or blender.Microcapsules sizes varied from 40-800 microns. Flexural strength tests, the 160mm x 4Omm x 20mm samples were used. Each sample was subjected to an applied load of 0.25 mm/min to induce micro cracking within the sample. The cracking is minor and internal only and meant to mimic micro scale damage and deformations that occur within the concrete after applied or natural stress, and prior to catastrophic failure. After one week, these samples were retested to see how much strength has been recovered after the initial damage. Was achieved by subjecting to 160mm x 40mm x 20mm samples to a three point bend test microcapsules proved to be an effective way of encapsulating the healing agent for a targeted release. The results from the compressive strength tests show that the capsules do not interfere with the cementitious matrix where the presence of the microcapsules helps the material perform at least10% better then the control samples.

H. M. Jonkersen titled Bacteria-based self-healing concrete. A typical durability- related phenomenon in many concrete constructions is crack formation. While larger cracks hamper structural integrity, also smaller sub-millimeter sized cracks may result in durability problems as particularly connected cracks inerease matrix permeability. As regular manual maintenance and

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repair ot concrete constructions is costly and in some cases not at all possible, inclusion of an autonomous sell- healing repair mechanism would be highly beneficial as it could both reducemaintenance and increase material durability. The functionality of various self-healing additives is investigated in order to develop a new generation ot sell- healing concretes Microscopic techniques in combination with permeability tests revealed that complete healing of cracks occurred in bacterial concrete and only partly in control concrete. The mechanism of crack healing in bacterial concrete presumably occurs through metabolic conversion of calcium lactate to calcium carbonate what results in crack-sealing. This biochemically mediated process resulted in efficient sealing of sub-millimeter sized (0.15 mm width) cracks. It is expected that further development ot this new type of self-healing concrete will result in a more durable and moreover sustainable concrete Which will be particularly suited for applications in wet environments where reinforcement corrosion tends to impede durability of traditional concrete constructions.

SUMMARY OF LITERATURE

- From the study of above literatures the following considerations are listed: Concrete 1s an inexpensive material to produce and is recyclable. Unfortunately, concrete is susceptible to many sources of damage. Cracks can form at any stage of its life and most begin internally where they cannot be seen for years until major repairs are needed.

- A number of approaches to induce self-healing in concrete have been attempted. Of these approaches, the most common are chemical encapsulation, bacterial encapsulation, mineral admixtures, chemicals in glass tubing, and intrinsic healing with self-controlled tight crack widths

- Chemical encapsulation utilizes self-healing chemical agents contained in microcapsules, which are dispersed uniformly within concrete and fracture to release a healing agent when a crack occurs. The bacterial encapsulation technique is similar, but bacteria that induce precipitation of calcium carbonate are used as the self-healing agent.

- Some mineral admixture approaches utilize expansive agents and geo- materials dispersed within a concrete matrix, which expand to fill cracks when damage occurs, the extent of self-healing in cracked concrete was found to be highly dependent on the crack width, with smaller cracks healing more completely and at a faster rate than larger cracks. In some cases with small crack widths, cracks may heal completely thus increase the strength of the concrete.

- Using encapsulated healing agents that are embedded inside the matrix, may be useful to obtain self-healing properties in concrete. Bending tests proved that after crack appearance and autonomous crack healing, up to 80% regain in strength and 60o regain in stiffness may be obtained.From this studies for increasing the efficiency of self-healing properties the bio CaCos wants to increase.

MATERIAL PROPERTIES

MATERIAL USED

CEMENT

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Cement is a fine powder, which when mixed with the water and allowed to set and harden can join different component or members together to give a mechanically strong structure. Although the percentage of cement in concrete is around 1%, the role of cement is very important in the strength and durability of concrete. Cement absorbs moisture and it undergoes chemical reaction termed as hydration. The bureau of Indian standards (BIS) has classified OPC in three different grades.

- 33 grade
- 43 grade
- 53 grade

In this research ordinary Portland cement of 43 grade (IS8112:1989). The total quantity of cement required was approximately estimated ,brought and stored in an air tight container.

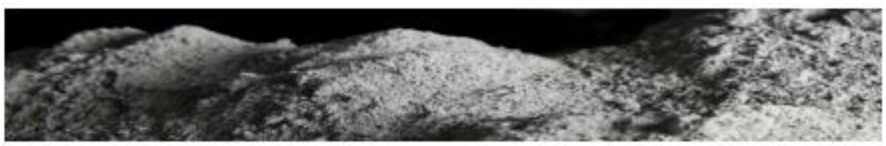

Fig 1: Cement

Properties of cement

Types of cement	Ordinary Portland Cement of 43 grade
Setting time	32 min
Specific gravity	3.15

- Fineness test
- Standard consistency test
- Setting time of cement
- Specific gravity of cement

WATER

Water plays a vital role in mixing as well as curing of concrete as it is the agent which initiates the reaction in cement and is also essential at the time of curing. Water used in concrete is preliminary supposed to be checked for harmful chemical presence which can have devastating effect on the concrete. Potable water available in the college campus was used for preparing concrete in the following study was used 1or the entire experimental investigation including curing of specimens,

COARSE AGGREGATE

Coarse aggregate should be cubical, or rounded shaped and should have granular or crystalline or smooth (but not glossy) non-powdery surface, Aggregates should be properly screened and if necessary washed clean before used. In this locally available quarry stone in good strength passing through 20mm and retained in 10 mm sieve conforming to IS 383-1987 is used.

Fig 3: Coarse aggregate

Properties of coarse aggregate

Specific gravity	2.45
Fineness	1.5
Size of aggregate	20mm

- Specific gravity
- Water absorptíon

FINE AGGREGATE

Fine aggregate shall consist of natural sand and or manufactured sand. Fine aggregate should be selected so as to reduce the water demand hence rounded particle are thus preferred to crush rock fine where possible. The finest fractions of fine aggregate are helpful to prevent segregation. For the fine aggregate river sand conforming to IS 383-1987 is used.

- Specific gravity
- Water absorption

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Fig 4: Fine aggregate

Properties of Fine Aggregate

Specific gravity	2.72
Fineness modulus	2.67

MIX DESIGN

Concrete mix design is designed as the appropriate selection and proportioning of constituents to produce a concrete with pre defined characteristics in the fresh and hardened states. In general, concrete mixes are designed in order to achieve a defined workability and durability.

The selection and proportioning of materials depend on:

- The structural requirement of concrete
- The environment to which the structure will exposed
- The job site conditions .especially the method of concrete
- Production, transport, placement, compaction and finishing
- The characteristics of the available raw materials.

The concrete mix has been designed for M20 grade as per 1S 10262- 2009.specified concrete grade involves the economical selection of relative proportions of cement, fine aggregate, coarse aggregate and cement. Although compliance with respect to characteristic strength is the main criteria for acceptance, it is implicit that concrete must also have desired workability in the fresh state and impermeability and durability in hardened state.

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The design of concrete mix involves the determination of the most rational proportions of the ingredients of concrete to achieve a concrete that is workable in its plastic stage and will developed the required qualities when hardened.

A properly mixed design concrete should have minimum possible cement

content without sacrificing the concrete quality to make it an economical mix. The proportions of materials will differ with different requirement. In general, a fresh concrete must be workable and hardened concrete must be durable and have the desired strength and appearance. Hence, design of concrete remains more of an art than a science.

MIX DESIGN METHODS

The mix design method being used in different countries are mostly based on the empirical relationship, charts and graphs developed from the experimental investigations. The various methods of proportioning are,

- Minimum void method
- Maximum density method
- Fineness modulus method
- British mix design(DOE) method
- American concrete institution method(ACI)method
- Kennedys method
- Arbitrary method
- Indian standard method

MIX DESIGN FOR M20 GRADE

Mix proportioning for a concrete of M20 grade is given in AI to A-ll.

STIPULATIONS FOR PROPORTIONING

1. Grade designation : M20
2. Type of cement: OPC 53 Grade conforming IS 12269
3. Maximum nominal size of aggregate: 20mm

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4. Minimum cement content: 300 kg/m (IS 456:2000)

5. Maximum water-cement ratio : 0.50 (Table 5 of IS 456:2000)

6. Workability: 100-120mm slump

7. Exposure condition : Moderate (For Reinforced Concrete)

8. Method of concrete placing:Pumping

9. Degree of supervision: ood

10. Type of aggregate: Crushed Angular Aggregates

11.Maximum cement content : 340 kg/mn

12.Chemical admixture type : Super Plasticizer ECMAS HP 890

TEST DATA FOR MATERIALS

a) Cement used: OPC 43 Grade conforming IS 12269

b) Specific gravity ot cement:3.15

c) Chemical admixture : Super Plasticizer conforming to IS 9103 (ECMAS HP890)

d) Specific gravity

- Coarse aggregate 20mm: 2.67
- Fine aggregate: 2.65
- GGBS:2.84 (JSW)

e) Water absorption

- Coarse aggregate : 0.5 %
- Fine aggregate (M.sand): 2.5 %

f) Free (surface) moisture:

- Coarse aggregate: Nil (Absorbed Moisture also Nil)
- Fine aggregate: Nil

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g) Sieve analysis:

- Coarse aggregate: Conforming to all in aggregates of Table 2 of IS 383
- Fine aggregate: Conforming to Grading Zone II of Table 4 of IS 383

TARGET STRENGTH FOR MIX PROPORTIONING

F”ck=fck + 1.65 s where,

f’ck =target average compressive strength at 28 days,

fck = characteristics compressive strength at 28 days, and S= standard deviation.

From Table I of IS 10262:2009, Standard Deviation, s =4 Nmm. Therefore, target strength= 25 + 1.65 x 4= 31.6 N/mm:. Hence the Mix ratio is 1:1:2

SAMPLE PREPARATION

SAMPLE COLLECTION

To attain these goals, materials were collected from various sources. Material collection is the basic and important step in any project. Yet, the material that is used in a study should not cause any damage to the environment. For the self- healing concrete the samples are prepared in various process. The samples are microorganisms, chemicals for healing agent, after preparation oI samples the survival test to be conducted for bacteria to check the amount of production of calcium carbonate.

SAMPLE CREATION OF BACTERIA:

By Isolation Process:

- Soil samples are collected from urea rich field.

1g of soil is dissolved in 25ml of distilled water and kept in incubator at 37 degree Celsius for one day.

- Serial dilution was done by using the above stock solution up to 10 dilution plates containing Mg minimal medium or nutrient agar (along with

% urea) by spread plate technique(0.1 ml).

- Incubate at 37 degree Celsius for 2-5 days.
- Cultures which forms zones are taken.
- Streaking was done on the plates containing Mo minimal medium on one plate and nutrient agar (along with % urea) on another plate(sub culturing).

- Incubate at 37 degree Celsius for 2-5 days.
- Then the cultures were grown in nutrient both (5% urea) for 2-5 days.
- Then it will used for analysis, the figure 8 shows that bacterial sample.

BACTERIAL STRAIN

The bacterial strain used in the experiments was B.substilus, B.licheniformis. These bacterial strain has a high urease activity (40 mm urea hydrolyzed. OD_ 1 h_), long survival time and can produce CaCcO3 in a simple and controllable way.

BACILLUS SUBSTILUS

- The medium used to grow B.substilus consisted of yeast extract and urea.

The yeast extract medium was first autoclaved for 20 min at 120°C and the urea solution was added which was sterilized by means of filtration through a sterile 0.22 Im Milipore filter.

- The final concentration of yeast extract and urea were 20 g/L. Cultures were incubated at 37C on a shaker at 100 rpm for 24 h.
- The concentration of bacterial cells was 109cells/mL.

BACILLUS LICHENIFORMS

- The B. licheniformisare prepared from spores obtained from PDA Medium after 72h. they were harvested, washed several times with distilled water, heated at 80'c for 30min and stored at 4 c. spores(4X 10) were suspended in 40mlL M20 medium.
- After incubation for 16h with vigorous shaking at 37 C, the culture was used to inoculate a 1.51 fresh M20 medium.
- The concentration of the bacterial cells is 109cells/mL.

SURVIVAL TEST OF BACTERIA

- In this experiment, it is tested to know how long the bacteria can remain viable and sustain high unease activity.
- Batches of 2 ml. bacterial solution (109 cells/ml) were added into a The vials were then closed tightly and put in the incubator at 57C. AAt
- Bacteria of each vial were inoculated into 100 mL sterile deposition sterile vial (12.5 mm (diameter) 46 mm (height), VwR).

certain time intervals, three vials were taken out from the incubator. medium (yeast extract 20 g/L urea 20 g/L and Ca (NO;)2.4H;0 79 g/L)

- The media were then put on the shaker (5TC, 100 rpm) tor three days. The amount of urea decomposed by bacteria after three days was calculated based on the total ammonium nitrogen measured in the deposition medium.

- Since one mole of urea (CO (NH;5) produces 2 mol of NH4, the amount of NH'4 can thus indicate the amount of urea decomposed, and hence the amount of CacO3 precipitation.

MECHANISM

SPHERIFICATION PROCESS

Spherification is a culinary process that employs sodium alginate and either calcium chloride or calcium lactate. When these chemicals come in contact it shapes a liquid into squashy spheres, which visually and texturally resemble roe.

In our study to incorporate the bacteria into the concrete specimens the Spherification process has been involved. Initially the chemicals sodium alginate and calcium lactate are prepared. The bacteria B.substilus and B.lacheniformis are added separately to the calcium lactate solution. Since the bacteria are activated it starts to feed on the calcium lactate. Now, into these bacteria incorporates calcium lacatae solution the sodium alginate is added as drops which forms a squeshy sphere layer which acts as a protective cover for the bacteria. This layer o solution is added to the concrete matrix to generate the self healing property.

SELF HEALING MECHANISM

The rate of self healing will be depending upon the growth of Bacillus.When the cracks occur the protective sodium alginate cover of the Bacteria gets cracked and the bacteria come into contact with the external environmental pressure. When the moisture enters into the crack, the calcium and the bacteria composites undergoes urealytic process.

Ca(NH2)2+2H20 CO32 + 2NH4

When the oxygen entersi nto the crack by environmental pressure the bacteria induce Calcium carbonate.

Ca(CsHsO3)2 + CO2 + Alkaliphilic bacillus CaCO3+ 5CO+ 5H2O

The excess carbonate 1ons obtained from urealytic process react with calcium ions and get more quantity of Calcium carbonate.

EXPERIMENTAL PROGRAM

DETAIL OF SPECIMEN

For the experimental program the specimen were casted as per specification given in the Table for M25 grade concrete. Total number of specimen casted is given in Table 2. The reinforcement detailing of the RC beam is given in fig 11. The concrete was casted by adding different percentage of self healing agent and normal concrete.

In the study, the self repair or self healing is carried out by the bacteria's B substilus and B.lichenformis. Tne bacteria were added at a quantity of 0.5ml, 1ml, 2ml. By compression test and flexure test the strength of the bacterial concrete of different percentage were found out.

The reports for the compression asS well as Tlexure test were formulated below. From the test report healing property and the strength gain in concrete is compared.

S.no	Specimen shape	Specimen size
1	Cube	15cm X 15cm X15cm
2	Beam	15cmX15cmX1.1m

Table 1 : Specification of specimens

Details	Cube	Beam
Conventional Concrete	9	1
Concrete with 0.5 ml of bacteria	9	-
Concrete with 1 ml of bacteria	9	-
Concrete with 1 ml of bacteria	9	2

STRENGTH PROPERTIES

COMPRESSIVE STRENGTH TEST

The test was carried out on 150 x 150 xI50mm size cubes, as per IS:516- 1959. The test specimens were marked and removed from the moulds and kept in room temperature. A 2000 KN capacity Compression Testing Machine (CTM) is used conduct the test. The specimen is placed between the steel plates of the CTM and load is applied at the rate of 140 kg / cm /min and the failure load in KN is observed from the load indicator of the CTM. Three specimen are crushed and average value is taken for result.

Compressive strength=PIA N/mm2 Where,

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P=Compressive load in N A=Area in mm

FLEXURE TEST

The test was carried out on 150x 150 x 1100 mm size beam with third point loading as per the IS: 516 -1959. The simply supported concrete beam is loaded by two point load placed at third points along the span. 1he load is monolithically increased until flexural failure occurs. Based on the peak load, the peak flexural stress within the beam is calculated. The beam specimens were tested and average value is taken for result.

Flexural strength (or) modulus of rupture (t b)

Fb) = PL /bd2

Where,

b =width of specimen (mm) d=failure point depth (cm) l=supported length (mm)

RESULT AND DISCUSSION

The concrete were casted as per Mix Design (IS0262:2009). With the chained specimens, the tests for strength properties were done.

To study the behavior of self healing Concrete the healing were added as 0.5ml 1 ml,2ml along the 2 % of the spherification solution.

The test result of conventional concrete, self healing concrete were compared. Hardened test was done 1or finding the mechanical properties such as compressive strength, flexure strength at age of 28 days respectively.

STRENGTH PORPERTIES

COMPRESSIVE STRENGTH TEST

The compressive test was done for the concrete for all the percentage bacteria addition at the age of 7, 14 and 28 days. An initial load was applied till a visible crack formation. Then the specimen was allowed to be healed for 12 days by the biomatic agent. The induced CaCO3gets filled in cracks. Finally the ultimate compressive strength. Testing specimens is shown in fig 12. The result are listed out in table. Strength of all specimens for all ages were compared and From the test report it is noted that 2ml addition of bacteria give high compressive strength than 0.5ml and 1 ml addition of bacteria in all 7, 14 and 28 days.

TEST RESULTS

The compressive strength f conventional concrete.,

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Table 3 : For conventional concrete

No. of days	**Comp. strength at first crack (N/mm^2)**	**Ultimate comp. strength (N/mm^2)**
7	6.13	16.98
14	**5.78**	20.5
28	7.56	25.8

For 0.5 ml addition of bacteria in 2 % f spherificaton solution the compressive strength (N/mm2)

Table 4 : 0.5 ml addition of bacteria

Table 4 : 0.5 ml addition of bacteria

B. Substilus B. licheniformis

No of days	Comp strength at first crack	Comp strength after healing	Ultimate Comp strength	Comp strength at first crack	Comp strength after healing	Ultimate Comp strength
7	4.6	10.6	16	5.5	9.5	17.8
14	5	11.5	21.3	6	10.9	20.0
28	5.78	12	26.8	6.5	11.2	28

For 1 ml addition of bacteria in 2 % of spherification solution the compressive strength (N/mm2)

Table 5 : 1 ml addition of bacteria

B. Substilus B. licheniformis

No of days	Comp strength at first crack	Comp strength after healing	Ultimate Comp strength	Comp strength at first crack	Comp strength after healing	Ultimate Comp strength
7	4.3	11.6	16	5.56	10.5	17
14	6.9	11.9	21.3	6.67	10.91	21.2
28	6.1	13.1	26.9	5.92	11.6	27.1

For 1 ml addition of bacteria in 2 % of spherification solution the compressive strength (N/mm2)

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Table 6 : 1 ml addition of bacteria

No of days	B. Substilus Comp strength at first crack	B. Substilus Comp strength after healing	B. Substilus Ultimate Comp strength	B. licheniformis Comp strength at first crack	B. licheniformis Comp strength after healing	B. licheniformis Ultimate Comp strength
7	6.5	11.9	16.7	6.13	11.5	17.73
14	6.72	12.9	20.8	6.03	11.7	21.81
28	6.34	13.6	27.31	6.1	12.9	27.32

FLEXURE STRENGTH TEST

This experiment was used to evaluate whether the material was able to recover some of its strength after acquiring some of the micro scale damage. First the specimen was loaded to initial failure, after the failure the specimen was left to heal for 12 days. During this period the solution released from the glass tubes to the CaCO3. The reaction occurs and the healing process whereas done in the specimen.

By the testing of flexure in the beam specimen obtaining the load 80kN and 9OkN attained at the period of 28 days. After the strength occurs the crack is filled by the healing agent, and the process of self-healing occurs up to 12 days. When the crack is healed by the healing agent the strength parameter will found for the specimen after 12 days obtaining 105kN and 117kN, it load increment take place after healing process attained.

HEALING OF CONCRETE:

The repair mechanism of the concrete is tested in the bacterial concrete. After the application of initial load the specimens were allowed for the healing process for the duration of 12 days by the biomatic materials. The healing process was undertaken under the condition of environmental pressure. After the 12 days period the healing process were keenly observed.

From the observation it is noted that the concrete has been undergone healing mechanism. From the specimens observation it is noted that the 2ml addition of bacteria had complete crack closure whereas the 0.5ml and I ml addition of bacteria had partial crack closure. It indicates the precipitation calcite has been taken place in the concrete due to environmental pressure. It also shows that increase in the addition of bacteria stimulates he precipitation of the calcite.

CONCLUSION

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- Healing agents that are embedded inside the matrix may be useful to obtain self-healing properties in concrete.

- The application is using bacteria to precipitate the cracks in concrete, with this method relatively large cracks can be closed by self-healing

- Both the bacteria shows result increase in stiffness and compressive strength compared to the conventional concrete.

- Among the bacteri's B.Substilus shows performance compared to B.licheniformis in strength parameter having balanced concentration and healing property.

- Since the concentration of Blicheniformis is more its performance efficiency is reduced. And also the culturing process of the bacteria is somewhat tedious compared whereas B.Substilus can be easily obtained.

- The premature cracks are healed within 12 days of crack formation environmental pressure

- From the study it is clearly founded that increase in addition of bacteria accelerates the repairing building mechanism in concrete.

- It also enhance reduction in post construction maintenance burden, thus leads to 50% reduction in maintenance cost f the structure which eventually increases the durability of the structures.

FUTURE SCOPE OF THE WORK

The present study can be extend for future work with consideration to the following points.

- To study self-healing mechanism to the various concrete structural members

- To select the suitable chemicals for the production of large amount Cac0s in existing concrete structures

- To study the amount of healing agent with various temperature levels used for self-healing process.

- To determine the various methods used for self-healing process.

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