International Journal of Recent Engineering Research and Development (IJRERD)
Volume No. 02 – Issue No. 01, ISSN: 2455-8761
www.ijrerd.com, PP. 21-30

SELF HEALING OF CONCRETE USING POLYMER TECHNIQUE

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Abstract: Self healing of concrete is better as normal concrete for big projects, where it can be used. The microcapsule proved to be effective way of encapsulated the healing agent for the targeted release.

CHAPTER 1
INTRODUCTION

1.1 GENERAL:

Concrete is exposed to external factors such as extreme heat, cold, stress, during service. Concrete shrinks and expands with variations in moisture and temperature. Cracks can occur when changes to accommodate these factors are not implemented in the design and development. Other factors that can affect concrete and its lifespan include shrinkage, design flaws or poor quality of construction materials. Concrete experiences various loading from heavy vehicles, earthquakes and strong winds. Due to these factors in addition to several more it is inevitable that reinforced concrete eventually develop cracks. When cracks originate in concrete structures, a sequence of serious events begins to occur within those structures. Not only do these cracks affect the functionality of the structure, but they also affect the durability and strength of the structure. In order to enhance concrete resistance to these defects and degradations, the innovation of self-healing concrete is promising.

Self-healing concrete can be defined as concrete that possesses self-healing agents, which will 'automatically heal' concrete structures, when cracks occur during their life cycle. Self healing agents may be transferred through strong core microcapsules, hollow reinforced fibers and even by forms of organic matter. All of these methods are currently undergoing testing and analysis in order to test their durability and longevity. This research deals with a number of self-healing chemicals that are used in the encapsulation process by using polymers techniques.

Eight key factors that affect the effectiveness of self-healing by encapsulation are discussed; these are (1) robustness during mixing, (2) probability of cracks encountering the capsules, (3) curing time and condition, (4) effect of empty capsules on concrete strength, (5) controllability of release of healing agent, (6) stability of healing agent, (7) sealing ability and recovery of durability and strength of concrete matrix and (8) repeatability of self-healing action.

1.2 OBJECTIVE:

The main goal of this report is to evaluate and to control specific parameters for the production of an effective self-healing matrix that can be utilized within the application of self-healing concrete. The healing process that has been chosen for this analysis is that of self-healing by capsulation techniques.

1.3 ORGANISATION REPORT:

Chapter2 shows the detailed literature review of various methods used for self healing of concrete by various technology with different aspects.
Chapter3 shows case studies of various method of self healing of concrete with reference to various journals and reference papers.
Chapter4 shows overall summary for various techniques used in self healing of concrete and keeps a point of discussion with its advantage and disadvantages.
Chapter5 provides us various references with the ideas of different engineers methodology.

CHAPTER 2
DETAILED LITERATURE REVIEW

2.1. INTRODUCTION:

Concrete is the most commonly used building material in the world. It is strong, durable, locally available and versatile. It is 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. Damage is caused by freeze/thaw cycles, corrosion, extreme loads, chemical attacks and other environmental conditions. Consequently, maintenance to concrete structures is frequent and costly. Billions of dollars are spent every year on buildings, bridges and highways for maintenance, making materials requiring less frequent repairs very appealing.The production of concrete is an energy-intensive process when mining, transportation and processing is considered. Its production level lies at about 2.35 billion metric tons per year and contributes an astonishing 10% of CO2 emissions into the atmosphere. Damage, deterioration and overall structural integrity are conventionally monitored through routine inspections and repair. This may involve surface repairs, admixtures, sealant applications, surface washing and corrosion monitoring. In the past decade, the building industry has taken a significant interest in engineering concrete as a smart material to alleviate issues such as excessive routine maintenance, excessive production and costs. One strategy to do this would be to mitigate micro scale damage through an autonomous method that senses and repairs cracks in a targeted way.

2.2 METHODS OF SELF HEALING OF CONCRETE:

1. Autogenous Self-Healing
2. Vascular Self-Healing
3. Capsule-Based Self-Healing(polymers techniques)
4. Cementitious composites self healing
5. Bio-concrete method of self healing
6. Bacteria based self healing.

2.2.1. Autogenous Self-Healing: [Yang et al. 2009; Jacobsen et al. 1996; Granger et al. 2007; Li and Li 2011]

Autogenous self-healing relies on the composition of concrete and is accomplished by hydration reaction of cementitous products within the matrix, or by reaction of polymeric substances in the matrix. Autogenous self-healing has been widely studied .One of the weaknesses of this approach is the limitation posed by crack width. Autogenous healing is primarily effective for very narrow cracks; different researchers studied the effectiveness of this technique in sealing cracks of different widths, of 5–10 μm, 200 μm, and 300 μm. It has been acknowledged that wider cracks that are deterimental to durability of concrete structures cannot be effectively healed by autogenous healing. Furthermore, a constant supply of water must be present to support the hydration process so that cracks can be completely sealed. Therefore, the phenomenon of autogenous healing may be more prominent in fresh or young concrete, whereas carbonate precipitation may be the pronounced mechanism at later stage.Several researchers attempted at using supplementary cementitous materials, such as fly ash and blast furnace slag, to stimulate autogenous healing. Materials like fly ash and slag hydrate at slower rate than cement,and therefore, unhydrated particles of such minerals promote autogenous healing at later stage of concrete. However, the disadvantage of this approach is that the healing agent is consumed in the process and may not be available for further hydration at later stage.

2.2.2.Vascular Self-Healing:[Neville et al., 2002]

The vascular approach of self-healing closely shows the vascular network system in the human body. A network of tubes can be installed in concrete to deliver a healing agent to the cracked/ damaged sites. In this approach, healing agents are confined in hollow tubes or network of tubes and supplied by an external source. There are two means of achieving self-healing by vascular approach: single-channel and multiple-channel systems. When only a single-component healing agent is used, the single-channel vascular approach is used; when it involves healing by the reaction of two healing agents, multiple channels are used. Although external supply of healing agent is effective, technically it is not self-healing per se, since it requires external intervention. Moreover, although feasible at laboratory scale, it is difficult to cast concrete with a network of pipes for vascular self-healing on actual construction sites. In many ways, the problem countered by these two a fore mentioned methods can be addressed by capsule-based self-healing(polymer technique).

2.2.3.Capsule-Based Self-Healing(polymer technique). : [Dong et al. ,2015].

In capsule- based self-healing, the capsules provide mechanical protection to the healing agents and only release them after being triggered by cracks (by capsule rupture or diffusion), moisture, air, or a change in pH of the pore solution in the matrix. In cases where cracking is the trigger mechanism, the capsules break and healing agent is pulled into the crack by capillary action. The capsulation strategy is capable of increasing the lifespan of chemical or biological healing agents and controlling their releases into the matrix. There is evidence suggesting that the capsule-based approach is versatile and the quality of repair is satisfactory, which is generally measured by recovery of mechanical and durability properties. However, the main challenge with the capsule-based approach is its repeatability over the long term. Concrete structures are subjected to multiple damage cycles throughout their service life and therefore a capsule-based system is expected to offer multiple instances of quality healing. Microcapsules can encapsulate limited amounts of repair agent and therefore most of the healing agent is exhausted under a single loading cycle and hence repeated healing over the long term is questionable. However, recent research efforts focused on smart release of healing agents. Therefore, although not very established at this point of time, capsules may be designed so that multiple healing cycles can be achieved. The effectiveness of healing under multiple loading cycles by incorporating healing agent in tubes; they found that recovery of stiffness decreases under multiple cycles of loading. Therefore, future research on repeatability of capsule based systems is needed. Depending on the capsulation technique used, capsules are either strategically placed at predicted locations of failure (e.g., tubular glass capsules) or are dispersed throughout the matrix as uniformly as possible (e.g., microcapsules).

2.2.4.Cementitious composites self healing:[Tae-Ho Ahn and Toshiharu,2010]

The serviceability limit of concrete structures by cracking might be overcome by crack control methodologies the enhanced service life of concrete structures would reduce the demand for crack maintenance and repair. In particular, the utilization of self-healing technologies has high potential as a new repair method for cracked concrete under the water leakage of underground civil infrastructure such as tunnel etc., This trend shows that it is necessary for both the industrial and research fields to develop concrete including self-healing crack. Therefore, the aim of this study is to develop a cementitious composite at normal or high water/cement ratios, the self-healing properties of concrete incorporating geo-materials as a partial cement replacement were investigated in terms of recrystallizations. This study focused on two primary issues: (1) experimental and analytical design of cementitious materials with self-healing capabilities, (2) development of a self-healing concrete using new cementitious materials at normal water/binder ratio [over W/B=0.45].

2.2.5.Bio-concrete method of self healing:[Schlangen et al.2010]

In this study the potential of bacteria to act as a self healing in concrete is investigated. Although the idea of use of bacteria and integrate them in the concrete matrix may seems odd at first ,it is not a microbiological view point. Bacteria naturally occur every where on earth not only on surface but also deep within. To the date the main conclusion of this ongoing researches are that the experiment done in this study show the alkaliphilic endospore forming bacteria intergrated in concrete matrix can actively precipitate calcium carbonate minerals. Water, needed for the activation of endospores can enter the concrte structure through freshly formed cracks.

2.2.6.Bacteria based self healing:[Mayur and Jayeshkumar ,2013]

Research leading to microbial Calcium Carbonate precipitation and its ability to heal cracks of construction materials has led to many applications like crack remediation of concrete, sand consolidation, restoration of historical monuments and other such applications. so it can be define as "The process can occur inside or outside the microbial cell or even some distance away within the concrete. Often bacterial activities simply trigger a change in solution chemistry that leads to over saturation and mineral precipitation. Use of these Bio mineralogy concepts in concrete leads to potential invention of new material called ―Bacterial Concrete". 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 genus Bacillus, along with a calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus, are 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 200 years.

2.3 SUMMARY:

Various methods of self healing of concrete which described different method to increase crack filling process using different techniques. 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, reinforced corrosion have been seen in various cementitious and stone materials. This will soon provide the basis for high quality structures that will be cost effective and environmentally safe but, more work is required to improve the feasibility of this technology from both an economical and practical view points.

CHAPTER 3
CASE STUDIES

3.1 INTRODUCTION:

It is well known that one of the weaknesses of concrete is its vulnerability to cracking. Cracks may occur when concrete is in a plastic state or after it has completely hardened. Concrete may crack due to plastic shrinkage, thermal stresses, settlement, drying shrinkage, weathering, corrosion of reinforcement, or due to applied loading. Concrete has low tensile strength and therefore concrete constructions are often combined with various types of reinforcement to resist tensile stresses. Although this is a measure to control concrete cracking, complete crack prevention is almost impossible.

3.2 CASE STUDIES ON:

Following are the case studies done by the researches to implement their ideas regarding self healing of concrete by various techniques so that crack filling process reduce the time of overall maintenance.

3.2.1 Encapsulation Technology and Techniques in Self-Healing Concrete[Harn Wei Kua et.al,2016]

Microcracks in concrete also affect durability by allowing ingress of corrosive substances into the concrete matrix, which lead to corrosion of steel and loss in tensile strength. Such occurrence may lead to more adverse problems such as spalling and even premature structural failure. Therefore, maintenance and repair are necessary to seal cracks to reduce permeability and restore durability of the structure. However, in some cases, manual repair works are difficult because cracks are invisible or their locations cannot be easily accessed. In Europe, half of annual construction budgets are allocated to repair works opined that“ enhancing the longevity of our built infrastructure will undoubtedly reduce the impact of mankind’s activities on the stability of the biosphere.”This implies that extending the service life of existing infrastructure can reduce the demand for new infrastructure, cost, and pollution. Damage management is an alternative concept to damage prevention, and is based on the principle that damage in structures is tolerable as long as it is healed or can be rectified in time . One such damage-management concept is self healing concrete. This concept is largely inspired from the wound healing mechanism of human body, which can heal itself up to a certain level of damage by releasing biological agents to the wounded spots. In general, there are three main approaches of self healing. These are elaborated in the next section.

The three broad approaches to self-healing in concrete, as mentioned by Van Tittelboom and De Belie 2013, are autogenous, vascular, and capsule-based self-healing.

Autogenous self-healing relies on the composition of concrete and is accomplished by hydration reaction of cementitous products within the matrix, or by reaction of polymeric substances in the matrix. It has been acknowledged that wider cracks that are detrimental to durability of concrete structures cannot be effectively healed by autogenous healing. This limitation was addressed by Li 2011, who proposed using engineered cementitous composites (ECC) containing synthetic fibers, such as polypropylene (PP) and polyvinyl alcohol (PVA), to restrain crack width. Furthermore, a constant supply of water must be present to support the hydration process so that cracks can be completely sealed. Therefore, the phenomenon of autogenous healing may be more prominent in fresh or young concrete.

The vascular approach of self-healing closely mimics the vascular network system in the human body. A network of tubes can be installed in concrete to deliver a healing agent to the cracked damaged sites. In this approach, healing agents are confined in hollow tubes or network of tubes and supplied by an external source. There are two means of achieving self-healing by vascular approach: single-channel and multiple-channel systems. When only a single-component healing agent is used, the single-channel vascular approach is used; when it involves healing by the reaction of two healing agents, multiple channels are used.

In capsule-based self-healing, the capsules provide mechanical protection to the healing agents and only release them after being triggered by cracks (by capsule rupture or diffusion), moisture, air, or a change in pH of the pore solution in the matrix. In cases where cracking is the trigger mechanism, the capsules break and healing agent is pulled into the crack by capillary action.The encapsulation strategy is capable of increasing the lifespan of chemical or biological healing agents and controlling their releases into the matrix. There is evidence suggesting that the capsule-based approach is versatile and the quality of repair is satisfactory, which is generally measured by recovery of mechanical and durability properties.

In the literature, much focus has been placed on autogenous self healing, but this review showed that self-healing by encapsulation has the potential to deliver higher quality self-healing, in terms of the wider range of crack width that can be healed and faster response to cracking in the matrix. As discussed, there are different approaches to self-healing by encapsulation, the quality of which can be evaluated in terms of eight effectiveness criteria. These properties also highlight the complexity involved in determining the best combinations for optimum self-healing. At the very least, before selecting a method for a specific intended purpose, factors such as crack width, crack type, nature of the crack formation process (that is, whether it is stabilized or dynamic), and locations of application should be ascertained.

3.2.2 Bacteria-based self-healing concrete.[Jonkers,2011]

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 increase matrix permeability. Ingress water and chemicals can cause premature matrix degradation and corrosion of embedded steel reinforcement. 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 beneficial as it could both reduce maintenance and increase material durability. Therefore, with in the Delft Centre for Materials at the Delft University of Technology, the functionality of various self healing additives is investigated in order to develop a new generation of self-healing concretes. In the present study the crack healing capacity of a specific bio-chemical additive, consisting of a mixture of viable but dormant bacteria and organic compounds packed in porous expanded clay particles, was investigated. 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. It is expected that further development of 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.

The bacteria to be used as self healing agent in concrete should be fit for the job, i.e. they should be able to perform long-term effective crack sealing, preferably during the total constructions life time. The principle mechanism of bacterial crack healing is that the bacteria themselves act largely as a catalyst, and transform a precursor compound to a suitable filler material. The newly produced compounds such as calcium carbonate-based mineral precipitates should than act as a type of bio-cement what effectively seals newly formed cracks. Thus for effective self healing, both bacteria and a bio-cement precursor compound should be integrated in the material matrix. However, the presence of the matrix-embedded bacteria and precursor compounds should not negatively affect other wanted concrete characteristics. Bacteria that can resist concrete matrix incorporation exist in nature, and these appear related to a specialized group of alkali-resistant spore-forming bacteria.

The outcome of this study shows that crack healing of bacterial concrete based on expanded porous clay particles loaded with bacteria and calcium lactate, i.e. an organic bio-mineral precursor compound, is much more efficient than of concrete of the same composition however with empty expanded clay particles. The reason for this can be explained by the strictly chemical processes in the control and additional biological processes in the bacterial concrete.

3.2.3 Recent advances on self healing of concrete:[Schlangen et.al, 2010]

In this paper an overview is given of new developments obtained in research on self healing of cracks in cement based materials and asphalt concrete. At university various projects are running to study self healing mechanisms. The first project that is discussed is Bacterial Concrete, in which bacteria are mixed in concrete, that can precipitate calcite in a crack and with that make concrete structures water tight and enhance durability. In a second project hybrid fiber reinforced cementitious materials are studied that can mechanically repair cracks when they occur. The last project described in this paper is on the raveling of porous asphalt concrete and how to heal this damage by incorporating embedded microcapsules or steel fibers. The state of the art results in all projects show that self healing is not just a miracle, but materials can be designed for it.

Bio-concrete: In this study the potential of bacteria to act as a selfhealing agent in concrete is investigated. Although the idea to use bacteria and integrate them in the concrete matrix may seem odd at first, it is not from a microbiological viewpoint. Bacteria naturally occur virtually everywhere on earth, not only on its surface but also deep within, e.g. in sediment and rock at a depth of more than 1 km. Various species of so-called extremophilic bacteria, i.e. bacteria that love the extreme, are found in highly desiccated environments such as deserts, but also inside rocks and even in ultra-basic environments which can be considered homologous to the internal concrete environment. Typical for many desiccation- and/or alkali-resistant bacterial species is their ability to form endospores. These specialized cells which are characterized by an extremely low metabolic activity, are known to be able to resist high mechanically- and chemically induced stresses and are viable for periods of up to 200 years.

Capsule-method: Bitumen can be considered as a two phase material with a liquid phase, called maltenes, and a solid phase, called asphaltenes. With time, the liquid phase is oxidized, disappearing and causing asphalt to become dry and brittle. To avoid this, maltenes have been traditionally applied on the road surface once signs of ageing start appearing. The problem is that this type of treatment is superficial, with what only the first centimeters from the surface are affected. To solve this, it was thought that the optimum way of adding maltenes to the road would be by mixing capsules filled with maltenes with the asphalt concrete. With this, aging effects could be avoided over the complete depth of the pavement.

Self healing techniques in three different materials are discussed. 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.

3.2.4 Crack Self-healing Behavior of Cementitious Composites Incorporating Various Mineral Admixtures[Tae-Ho Ahn et.al, 2010]

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 concept 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. Moreover, a self-healing concrete was fabricated by ready-mixed car in a ready-mixed concrete factory, then used for the construction of artificial water-retaining structures and actual tunnel structures. 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 re-curing for 3 days and the crack width decreased from 0.22 mm to 0.16 mm after re-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. From these results, it is considered that the utilization of appropriate dosages of geo-materials has a high potential for one of new repairing methods of cracked concrete under the water leakage of underground civil infrastructure such as tunnels. the aim of this study is to develop autogenous healing concrete using various mineral admixtures for practical industrial application. Research has been done on the healing of cracks in aged concrete, but it seems that very little is known about the actual healing mechanism and its conditions. The mechanism is generally attributed to the hydration of previously unhydrated.

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.

3.2.5 "**Use of silica gel or polyurethane immobilized bacteria for self-healing concrete."[Wang et al. 2012b]:**

In capsule- based self-healing, the capsules provide mechanical protection to the healing agents and only release them after being triggered by cracks (by capsule rupture or diffusion), moisture, air, or a change in pH of the pore solution in the matrix. In cases where cracking is the trigger mechanism, the capsules break and healing agent is pulled into the crack by capillary action. The capsulation strategy is capable of increasing the lifespan of chemical or biological healing agents and controlling their releases into the matrix. There is evidence suggesting that the capsule-based approach is versatile and the quality of repair is satisfactory, which is generally measured by recovery of mechanical and durability properties. However, the main challenge with the capsule-based approach is its repeatability over the long term. Concrete structures are subjected to multiple damage cycles throughout their service life and therefore a capsule-based system is expected to offer multiple instances of quality healing. Microcapsules can encapsulate limited amounts of repair agent and therefore most of the healing agent is exhausted under a single loading cycle and hence repeated healing over the long term is questionable. However, recent research efforts focused on smart release of healing agents. Therefore, although not very established at this point of time, capsules may be designed so that multiple healing cycles can be achieved. The effectiveness of healing under multiple loading cycles by incorporating healing agent in tubes; they found that recovery of stiffness decreases under multiple cycles of loading. Therefore, future research on repeatability of capsule based systems is needed. Methods explain the healing by the microcapsule-based approach when a crack ruptures the capsule. Depending on the capsulation technique used, capsules are either strategically placed at predicted locations of failure (e.g., tubular glass capsules) or are dispersed throughout the matrix as uniformly as possible (e.g., microcapsules).

A variety of encapsulating materials, such as glass tubes, ceramic tubes, lightweight aggregates, and polymers have been used in developing self-healing action in concrete. Polymeric microcapsules are very frequently used and they are prepared by an oil-in-water dispersion mechanism of the polymer material, based mainly on the mini emulsion polymerization technique . Urea and formaldehyde are made to react in the liquid phase, which eventually becomes cross-linked to form the urea formaldehyde (UF) capsule shell wall. The pre polymer that is formed by reaction in the water phase can be deposited to give a rough texture to the microcapsules. This can help to improve bonding with the cementitous matrix.

A method using a sonification technique and hydrophobic solution for stabilization of a dicyclopentadiene (DCPD) healing agent for synthesizing UF microcapsules. Capsules with diameters of 220 nm and shell wall thickness of 77 nm were produced successfully with a more uniform shell wall. However, the literature mentions several problems with nano sized capsule debris accumulating in the host matrix and these can even initiate cracking. Different healing agents such as epoxy resins, polyurethane, and methyl methacrylate (MMA) were tested; the best result was obtained from the MMA–polyurethane combination.

Spherical capsules used to encapsulate a sodium silicate solution. Rupture of capsules released the solution into the matrix and the reaction took place with calcium hydroxide to form calcium silicate hydrate (C-S-H) that healed the concrete crack. .An amine based hardener was separately dispersed into the matrix. Once it properly cured, the epoxy that was released upon rupture of the capsules reacted with the hardener and healed the cracks. The epoxy polymer that was chosen had low viscosity between 250 and 500 mPas, and so it could flow smoothly into cracks and provide effective healing.

Healing takes place through a polymerization reaction of the epoxy resin with the hardener. Its also encapsulated tung oil or calcium hydroxide with spherical microcapsules made of a gelatin shell. In other research efforts microcapsules made of silica gel with oil core were used. The oil core phase consisted of MMA monomer as the healing agent and triethylborane (TEB), which acted as catalyst to heal microcracks.

Encapsulated spores of Bacillus sphaericusina melamine-based microcapsule system that also contained an inert material for protection of the spores. Bacteria concentration of about 109 cells/g of dry microcapsule was added. Crack healing efficiency measured in terms of the ratio of healed crack to initial crack area showed a maximum healing rate of 80% (under wet-dry curing); maximum healed crack size recorded was 970 μm (under water curing). In an earlier study used diatomaceous earth (DE) as a carrier for Bacillus sphaericus. This species was made to react with hydrolyzed urea provided in the cementitous matrix to precipitate calcium carbonate. Cracks of width between 0.15 and 0.17mm were found to be partially or completely healed. However, DE tends to absorb high quantity of water and dry up the mortar. Another problem is the formation of small amount of excess urea or calcium nitrate crystals that may affect concrete strength.

Special Additives in the Cement Matrix was used hydrogel-microencapsulated bacteria spores and bio reagents (nutrients for bacteria, urea, and calcium nitrate in this case) in their study. The main advantage of hydrogel is its capability to absorb and retain moisture over a long period of time. The encapsulated spores could grow into activecells and precipitate calcium carbonate by urea decomposition when there were sufficient water and nutrients in the hydrogels. Maximum crack width healed was around 0.5mm and a maximum decrease in water permeability of about 68% was observed.

ENCAPSULATION PROCEDURES: [Tseng, 2005]

There were over 100 trials attempted that involved the stabilization for the two different microencapsulation methods that were utilized for DCDP, as well as sodium silicate. The first microencapsulation procedure that was attempted was that of the Autonomic. This was one of the first attempts to the microencapsulation procedure utilizing the Urea-Formaldehyde method. This method focused on developing a procedure that would control the properties of the microcapsule geometry, and its mechanical triggering system .When evaluating the wall thickness parameters, it was understood that microcapsule walls that were too thin would fail during the manufacturing process. In retrospect, capsule shells that are too thick will not allow wanted breaking or fracturing of the shell as the crack penetrates through the microcapsules plane. This method also achieved a specific robustness, virtual toughness, and a strong interface with the matrix and the microcapsule itself. This focus of interest provided a basic orientation and baseline to begin further studies and trials.

A more defined and developed process of micro-encapsulation using the urea formaldehyde method was developed by [Brown et al. 2003]. The in-situ encapsulation method for water-immiscible liquids, by the reaction of urea with formaldehyde at acid pH, which was outlined .The foundation of this extensive method.

Although the shell wall thickness was analyzed and thoroughly explained, there is a minimum amount of literature, which incorporated information to specifically control its parameters. For example, it was annotated that too much ammonium chloride or resorcinol, reduced quantities of DCPD, tainted beakers, an unbalanced or unaligned mixer and lower initial pH will increase the thickness of the microcapsules shell wall. With certain standards and practices in place, all of these factors can be controlled. However, if there was a desire to change the thickness of the capsule wall, the pH would be the likely candidate for evaluation.

Encapsulation of sodium silicate has been successfully accomplished by using the polyurethane micro-encapsulation procedures only. This process, also using in situ synthesis, is an interfacial polymerization, which was adapted from. The following chemicals were utilized during this process: Span 85, polyethylene glycol (PEG), toluene, methylene di iosocyanate (Basonat), dibutyl tin dilaureate, etc. Although theoretically possible, micro-encapsulation of the Sodium Silicate using the Urea-Formaldehyde method has never been successfully accomplished before.

3.3 SUMMARY:

Various approach of the techniques in self healing of concrete. we have focus on Autogenous Self-Healing, Vascular Self-Healing Capsule-Based Self-Healing (polymers techniques), Cementitious composites self healing, Bio-concrete method of self healing, bacteria based self healing. But review shows that self healing done by capsule based (polymer technique) has great durability, and high potential to deliver higher quality of self healing. In terms of wider range of cracks width that can be healed and faster response to cracking in the matrix can be done easily.

CHAPTER 4
SUMMARY

4.1 INTRODUCTION:

Recent studies in the literature have demonstrated the ability of self-healing processes to be effective in enhancing the overall life of concrete. The main goal of this project is to evaluate and to control specific parameters for the production of an effective self-healing matrix that can be utilized within the application of self-healing concrete. In this paper self healing techniques in different materials are discussed. 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

4.2 OVERVIEW COMPARISION:

Various methods has been compared below showing their advantages and disadvantages of different methods of self healing of concrete with reference to their methodology.

TABLE NO: 4.1

Approach	Methodology	Advantages	Disadvantages
1.Autogenous self-healing	➢ Hydration of unhydrated cement particles. ➢ Dissolution and carbonation of calcium hydroxide. ➢ Supplementary cementitous material (SCM) and expansive agent.	➢ High recovery of mechanical properties possible. ➢ Healing possible under different exposure conditions. ➢ Healing late in the service lifespan of concrete is possible due to slow hydration of SCMs	➢ Use of high amount of cement is not sustainable. ➢ Performance depends on age of concrte and age of cracking. ➢ Continous exposure to water is needed. ➢ Expansive agents may cause micro cracking in the matrix.
2.Vascular self-healing	➢ Vascular approach	➢ Large amount of healing agents can be supplied and macro cracks can be healed. ➢ Potential for higher recovery of mechanical strength and durability.	➢ Difficult to cast network of tubes on bigger scales. ➢ Introduction to supply tubes may weaken the concrete structure. ➢ Strategic placement of glass capsule is needed at zone of cracking.

3.Capsule based system.	➢ Encapsulation of chemicals. ➢ Encapsulation of bacteria. ➢ Encapsulation of admixtures	➢ Respond to multiple cracking at same time. Satisfactory recovery of mechanical and durabilty property . ➢ Environmentally friendly mechanism.ppt compatible with matrix. ➢ Easy to design admixture content.Mix proportion can be stabilize with requirement.	➢ Intro of many glass tubes capsules can weaken the concrete structure. ➢ Recycling rate of concrete with chemicals agents may be low and disposal may not be enviornment friendly. ➢ Effectiveness is highly dependent on availabilty of moisture. ➢ High cost of production of spores for effective self healing.
4.Cementitious composites for self healing	➢ Effects of geo-materials on self healing ➢ Polyurethane microcapsule synthesis.	➢ geo materails helps in easy formation of calcium molecules. ➢ capsule technique reduces the process of corrosion.	➢ Availability of geo-materails is scare of same concentration. ➢ Design of capsules is tremendously difficult.
5.Bio-concrete	➢ Bacteria intrusion technique for concrete .	➢ Easily availabe every where on surface or deep inside of earth ➢ Ability to long lasting durabilty of concrete.	➢ Water is main source for activation of bacteria. ➢ Doesnot improve strength of structure after self healed.
6.Bacteria based self healing	➢ use of calcium carbonate for healing purpose	➢ Easily available in nature also used for concrete crack healing.	➢ Due to hydration property of calcium requires more water for curing process

As compared above various methods of self healing of concrete, Capsuled based system is more durable than as compared to other methods with respect to their methodology.

4.3 SUMMARY:

Self healing concrete is better as normal concrete for big projects where it can be used**.** The microcapsule proved to be effective way of encapsulating the healing agent for the targeted release. With this Self healing of concrete method relatively large cracks in reinforced concrete can be filled. Methods doesnot leads to strength improvements of the structure but by filling cracks the path of the reinforcement is blocked. Cracks can be filled in this way such that leakage can be stopped. Especially in underground structure where repair is difficult and impossible self healing concrete has great future.

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