RESEARCH ARTICLE OPEN ACCESS

Development of Self Repairable Durable Concrete

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Abstract
In Civil and structural engineering concrete is basic material. Mainly in RCC and prestress concrete its carry major part of static and dynamic loads. During the serviceability of structure concrete is subjected to different damages. The common approaches for repair of Structural concrete are: Polymer Injunction, External prestressing, Geomembranes and Polymer wraps. Application of this technique is useful in seek and repair of ductile and brittle failure. The above techniques are based on addition of a repair material to concrete from outside to inside of structural members. We are going to develop the self-repairable concrete by adding the materials from inside the concrete to repair cracks or damages.
Our technique to develop self-repairing concrete consists of embedding repairing materials in hollow ducts in the repairing zone before it is subjected to damage. Therefore when cracks occurs this repairs materials will get released from inside and it will enter the repairing zone. Where it will penetrate into cracks and rebound to mother cement and material of structure and it will repair the damage.
Key words: Concrete – Serviceability – Cracks- Epoxy resins- Repair.

I. Introduction

In Structural Engineering concrete is basic material used in R.C.C & Prestressed structures. The common approach for repair of structural concrete are: Polymer Injunction, External prestressing, Geomembranes and Polymer wraps. By applying this technique we can seek a ductile and brittle failure. The above technique is based on addition of a repair material to concrete from outside to inside of structural members. We are going to develop the self-repairing concrete system by adding the materials from inside the concrete to repair.

Our technique to develop self-repairing concrete consists of embedding repairing materials in hollow ducts in the repairing zone before it is subjected to damage or crack. Therefore when cracks occurs this repairs materials will released from inside and it will enter the repairing zone through cracks. Where it will penetrate into cracks and rebound to mother material of structure being repaired. The cracking and damages associated with low tensile strain capacity. This is important because in this way the material acts in an extensible manner. Further it does cracks and show ductile behavior but instant repair of cracks and damage assures that deterioration does not accompany with this “Cracks then Repair” behavior. Thus we repair the problem where it occurs and just in time automatically without material intervention.

Long term durability can be achieved by dimensional stability which means less stress from thermal contraction, autogenously shrinkage and drying shrinkage. Hence technique we utilized does precisely that it adds more materials to the concrete repair zone from inside upon demand when it is triggered by events such as cracking or shrinkage. To develop self-repairing concrete various technique have been proposed for repair by which temporary solutions concrete is brittle materials and dimensionally unstable because of movement the usual repair is of no use. The techniques that we are going to use or develop self-repair and unite most crucial qualities necessary for successful repair system. Our approach consist to address the bonding problem of repair material from inside the concrete therefore definitely better technique compared to other methods it is seen that self-repairing performs better because the adhesive is flexible itself and keep on releasing the each brittle failure that is cracks. The ability to fill in for dimensional gaps has been shown to work with self-repairing adhesives that grow larger in volume. The internal released stiff adhesive are less brittle, more ductile and stronger in tension. This type of technique is use full for structural member subjected to bending, shear cracks, etc. This approach of self-repairing is useful for having bridges prestressed box girders where dynamics, moving loads cyclic loads are in huge quantity and development of minor to major cracks possibility is more. In this development of self-repairing concrete our approach is that transformed the entire structure into a ductile materials, where energy was dissipated all over as cracks formed and consequently catastrophic failure due to enlargement of any one cracks was prevented.

Hence our approach consist of embedding repair material in ducts in cracking or tension zone before it subjected to damage. Therefore when cracking occurs, this repair material is released from inside and enters in damage zone/area, where it penetrates into cracks and rebounds to the mother material of structure and structure being repair.

II. Scope of Work

The main scope of present research work is to develop self-repairing durable concrete. While casting the structural member the repairing chemicals are inserted or store in ducts and the repair chemicals can be automatically released when structural members subjected to damages by external loads and development of cracks starts. Same will be seal to mother materials with equivalent strength, etc. Self-repair chemicals are embedded continuously in hallow ducts that fills the cracks, when and where they occurs. The chemical properties will be best as per design like strength, stiffness, viscosity, Final setting time, temperature to withstand etc.

III. Work Executed by different Researchers

1. "Development of Self Repairing Durable Concrete." Dr. Carolyn Dry (1994)

In literature survey last 20 years different research has develop the self-repairing techniques in different country under different climatic conditions, assumptions, and materials, etc. Out of which Dr. Carolyn Dry from USA has developed the practical technique of Development of self-repairing durable concrete. In his work investigation was made into development of Transparent polymer matrix composites that have the ability to self-repair internal cracks due to dynamic loading; in his work focused on cracking of hollow ducts disposed in a matrix and subsequent release of repair chemicals in order to visually assess the repair and speed of repairs in the impact test the polymer specimen was released in ten seconds. An Epon epoxy sample containing two epoxy in small tubes was subjected to impact in a Dynastic machine the result wherever considerably correct. In few seconds the two part adhesives has filled all contiguous crakes even though no fibers had been directly hit the adhesive raced around and filled the circular crack, an artificial of testing caused by the edge of impact machine. Adhesive flow set up and repair was accomplished within less than less seconds.

2. "Self-healing polymer composites: Mimicking nature to enhance performance"
Prof. R.S Trask, Prof. H.R Willams and Prof. I Bond (March, 2007)

Department of Aerospace Engineering, University of Bristol U.K utilized the concept of nature in which most of them are themselves self-healing composite materials.

The bio inspired concept after the designer an ability to incorporate secondary functional material capable of counteracting service degradation whilst still achieving. The primary structural requirement in most of the materials in natural condition it has themselves self-healing composite materials. This research is developed for fiber reinforcement polymeric composite materials most of which are bio inspired by observations of nature.

In this research work the researcher has a key focus on current scientific to the development of bioinspired material system. Naturally occurring materials in animals and plants have developed into highly sophisticated, integrated, hierarchical structure that commonly exhibit multifunctional behavior. In this work, light weight, high strength, and high stiffness fiber reinforcement polymer composite materials are leading contenders as components materials to improve the efficiency and sustainability of many forms of transports the researcher used the concept of self-healing by nature.

Similarly in this work the area of interest is based upon a biological, bleeding approach to repair i.e. Microcapsules and hollow. Fibers when the microcapsules are ruptured by progressing crack; the monomer is drawn along the fissure where it comes into contact with a dispersed particular catalyst. The key advantages of self-healing approach is the ease with which they can be incorporated within bulk polymer materials more recently microcapsules have been applied to improve the fatigue life of an epoxy bulk polymer with in-situ healing , crack arrest and an improved fatigue life of up to 213 %.

After applying different approach to develop self-repairing concrete. The concluding remark is that constant improvement have been made on composite materials, manufacturing process and structural design, the problem of initiation, propagation and tolerance has limited the acceptance of composite materials in all engineering discipline. It is the possibility to repair damaged structure that is increasingly of interest to composite designers seeking lower mass structures with increased service life.

3. "Development of Self-Healing Structural Composite Materials" Prof. S.R White & others from Department of Aeronautical and Astronautical Engineering Department of Applied Mechanics. University of Illinois USA. (January, 2000)

In the research of self-repairing concrete, micro cracking induced by thermal and mechanical fatigue is also long standing problem in polymer adhesive. In this work researcher report a structural polymetric material with the ability to automatically heal cracks. The materials incorporate a microencapsulated healing agent that is released upon crack instruction polymerization of healing agent is then triggered by counteract with embedded catalyst, bonding the crack faces. The fracture experiment shows 75 % recovery in toughness and they expect that our approach will be applicable to other brittle material systems (including ceramics and glass).
The method they adopted is to prepare microcapsules in situ polymeration the chemical like urea, resorcinol and ammonium chloride in water and recommended procedure the casual is prepared.

4. "Self-healing in polymer and polymer composites" Prof. Y.C Yuan & others From Chemical Engineering Department Zongshan University, China. (February, 2008)

In this research work of Prof. Y.C Yuan the focus is on developing lifetimes for structure and coalescences of micro cracks would bring catastrophic failure of materials. Hence early sensing, diagnosis and repair of micro cracks become necessary for removing the latent perils. Hence self-repairing polymers and polymer composites have attracted increasing research interest. The attempts have been made to develop solution in this field. The researcher work reviews state of art of the achievement of self-repair of concrete.

Polymers and polymer composites have been widely used in tremendous engineering fields because of their advantages including light weight, good processibility, chemical stability in any atmospheric conditions, etc. However, long term durability and reliability of polymeric materials are still problematic when they serve for structural application. Exposure to harsh environment would easily lead to degradations generated in service, which would bring about catastrophic failure of the materials and hence significantly shorten lifetimes of the structures. Since the damages deep inside materials are difficult to be perceived and to repair in particular, the materials had better to have the ability of self-healing. In fact, many naturally occurring portions in animals and plants are provided with such function. In the case of healing of a skin wound, for example, the defect is temporarily plugged with a fibrin cloth, which is infiltrated by inflammatory cells, fibroblasts, and a dense capillary plexus of new granulation tissue. Subsequently, proliferation of fibroblasts with new collagen synthesis and tissue remodeling of the scar become the key steps. For healing of a broken bone, similar processes are conducted, including internal bleeding forming a fibrin clot, development of unorganized fiber mesh, calcification of fibrous cartilage, conversation of calcification into fibrous bone and lamellar bone.

In the case of extrinsic self-healing, the matrix resin itself is not a healable one. Healing agent has to be encapsulated and embedded into the materials in advance. As soon as the cracks destroy the fragile capsules, the healing agent would be released into the cracks planes due to capillary effect and heals the cracks. In accordance with type of the containers, there are two modes of the repair activity: 1) self-healing in terms of healant loaded pipelines, and 2) self-healing in terms of healant loaded microcapsules. Taking the advantages of crack triggered delivery of healing agent, manual intervention might be no longer necessary.

Achievements in the field of self-healing polymers and polymer composites are far from satisfaction, but the new opportunities that were found during research and development have demonstrated it is a challenging job to either invest new polymers with inherent crack repair capability or integrate existing material with novel healing system. Interdisciplinary studies based on tight collaboration among scientists are prerequisites for overcoming the difficulties. Comparatively, extrinsic self-healing techniques might be easier for large scale usage for the moment.

5. "Modeling particulate self-healing materials and application to uni-axial compression." Prof. Olaf Herbst & Stefan Luding. (2008)

Using an advanced history dependent contact model for DEM simulations, including elastoplasticity, viscosity, adhesion, and friction, pressure sintered tablets are formed from primary particles. These tablets are subjected to unconfined uni-axial compression until and beyond failure. For fast and slow Deformation they observe ductile-like and brittle softening, respectively. They propose a model for local self-healing that allows damage to heal during loading such that the material strength of the sample increases and failure/softening is delayed to larger strains. Local healing is achieved by increasing the (attractive) contact adhesion forces for those particles involved in a potentially breaking contact. They examine the dependence of the strength of the material on (a) the damage detection sensitivity, (b) the damage detection rate, and (c) the (increased) adhesion between healed contacts. The material strength is enhanced, i.e., the material fails at larger strains and reaches larger maximal stress values, when any of the parameters (a)–(c) is increased. For very large adhesion between the healed contacts an interesting instability with strong (brittle) fluctuations of the healed material's strength is observed.

6. "Self-healing properties with various cracks widths under continuous water leakage." Prof. A. Hosoda & S. Komatsu, Prof.Yokohama National University.

Crack healing properties of 3 mix proportions under continuous water leakage were investigated by observation with microscope and water permeability test. Self-healing concrete under continuous water leakage showed better healing performances than cured in still water. An improved type self-healing concrete showed remarkable decrease of crack width with water passing through crack all the time.

Several researches have been reported about self-healing concrete containing admixtures such as carbonate compounds or expansive additive whose water to binder ratio was around 25–60% (Hosoda, 2001, 2007). They reported that when water was supplied after cracking, healing of crack was observed due to additional expansion of concrete near the crack or due to the precipitation of new hydrates. Healing of crack was verified in terms of water tightness by water permeability test. In all these researches, specimens were cured in still water after cracking. No research has been conducted to verify healing performances of self-healing concrete with water passing through the crack. In this study, self-healing performances of 3 mix proportions including the one which showed very good performance in our past research are verified under continuous water leakage. Crack width is set in 3 levels, such as 0.1 mm, 0.2 mm, and 0.4 mm. Half of the specimens are cured in still water, and the others are subjected to water head and continuous water leakage just after cracking. Healing performances are verified by the observation with a microscope and by water permeability test.

Crack healing properties of 3 mix proportions under continuous water leakage were investigated by observation with microscope and water permeability test. Normal concrete, self-healing concrete whose good performance verified in our past research, and an improved type self-healing concrete were tested in this study. Self-healing performance was investigated in two curing conditions. One is curing in still water after introducing cracking. In the other curing condition, specimens were subjected to continuous water leakage through crack. Self-healing concrete under continuous water leakage showed better healing performances than cured in still water. The improved type self-healing concrete showed remarkable decrease of crack width with water passing through crack all the time. In this study, crack of 0.4 mm width of the improved type self-healing concrete was healed under Continuous leakage. The initial water flow in that case was much larger than the limiting water flow for self-healing exhibited in a past research. A possibility that high alkalinity of surrounding water may decrease the self-healing performance related to the precipitation of $CaCO_3$.

7. "Using natural wood fibers to self-heal concrete" Prof. M.R. de Rooij, S. Qian, H. Liu, W.F. Gard & J.W.G. van de Kuilen ,Delft University of Technology. (2009)

Materials science has improved qualities of materials tremendously by dedicated engineering work. When, for example, a material is not strong enough, the cause will be identified, composition and processing of the material altered, until it results in a material being stronger, hence having improved properties. Such success stories can be identified for almost every property of a material. However, in this line of improvement the basic starting point has almost always been to raise the levels, set a new record (in our example make it stronger). Width hindsight, all strategies to improve the strength and reliability of materials developed over the past 20 centuries are ultimately based on the paradigm of damage prevention, i.e. the materials are designed and prepared in such a way that the formation and extension of damage as a function of load and/or time is postponed as much as possible (Van der Zwaag, 2007). Damage is defined here as the presence of micro- or macroscopic cracks not being present initially. However, in recent years it has been realized that an alternative strategy can be followed to make materials effectively stronger and more reliable through damage management, i.e. materials have a built in capability to repair the damage incurred during use. Cracks are allowed to form, but the material itself is capable of repairing the crack and restoring the functionality of the material. The material is self-healing.

In all modesty, it should be mentioned that self-healing is not something very new in materials science. The self-healing capability has been a property which was sometimes there by coincidence rather than intentionally imposed. A well-known example is the mortar used by the Romans for the construction of their buildings and large infrastructural works (Riccardi, 1998). The exceptional durability of these structures is the consequence of micro-cracks closing spontaneously due to a chemical reaction between the mortar and the moisture in the air leading to controlled dissolution and re-precipitation (Sanchez-Moral, 2004). Hence, it is fair to say that concrete-like materials have a good track record for self-healing to start from. However, the previous example also highlights one of the key parameters for successful self-healing: repair material should be transported from the bulk material to the place of damage (the crack). It is in this process part that some of the developments in self-healing materials are taking place. Glass vials with repair agent, for example, have been a reported option (Dry, 1994). Another option is pursued in this paper focusing on the transport properties of wood fibers. The paper describes various options to choose wood fibers, preliminary results on how to obtain single wood fibers and initial experiments on crack width. First however, some boundary conditions for concrete are discussed based on earlier research work.

In this article a very first inside look has been presented on the possible concepts of using natural fibers to self-heal concrete. Preliminary literature research has shown that the boundary conditions for a successful application of wood fibers in concrete can be met.

However, it has also been observed that many and also very practical obstacles in the research still have to be cleared. To name a few that have been mentioned throughout the article:

– obtaining (bundles of) fibers in enough quantity to perform the research,
– making a mixture composition in which the cracks remain small enough for self-healing to have a chance,
– producing fibers that break even with these very small crack widths,
– producing a coating that keeps the repair agent in the fiber during mixing of the concrete and during Undamaged service life of the concrete,
– producing a coating that is not so strong, that it will prevent the fiber to break.

As we know it is very well possible to manipulate the properties of the natural fibers as much as it is Possible to tune the properties of the future coating on the fiber, we are looking forward to the challenging research in the new field of self-healing materials.

8. "Developed Self-repairing material systems" Prof. Hartmut Fischer has, TNO Science and Industry, Eindhoven, The Netherlands.

Currently, most industrial materials rely entirely on passive protection mechanisms; such mechanisms readily applicable and universal for many different materials systems. However, they will always stay passive, and therefore their lifetime and functionality is limited and related to the amount of protective additives and the intensity of their consumption. Therefore, better, and preferentially active process for the protection/ repair of damaged materials—self-repairing processes— were developed and need to be developed further. Although it sounds futuristic or like a fiction in the modern, trendy times, which in many ways affects also directions of research; self-healing of material systems exists already for a long time in all sorts of systems of materials or functionalities. The aim of this work is to go beyond the scope of a classical review the ones published recently in this field which almost entirely focused only onto polymeric systems. In this work, an analysis of the underlying functional and constructional principles of existing natural and synthetically self-healing systems spanning over a range of classes of materials is given leading to general rules and principles for the design of new and application tailored self-healing material systems.

Self-healing is an intrinsic property of living organisms, enabling them to cope with all sorts of damage or injury they experience during their lifetime. This repair occurs with essentially no external intervention. Thus, wounds heal, broken bones heal, and even lost parts of living bodies (lizard tails etc.) can be replaced in some cases. Some natural self-healing composite systems such as bones go beyond simple healing to the extent that they remodel themselves continuously. Damaged material is removed and replaced by new material and over-designed material is also removed and structures under stress are enhanced by additional material. To enable this process, specific cells entrapped in the bone tissues act as strain sensors and feel large deformations. Subsequently, signals are sent to cells responsible for removing or forming material (bone).

9. "Fracture Testing of a Self-Healing Polymer Composite" By E.N. Brown, N.R. Sottos1 and S.R. White Department of Theoretical and Applied Mechanics Department of Aeronautical and Astronautical Engineering University of Illinois Urbana Champaign, Urbana.

Inspired by biological systems in which damage triggers an autonomic healing response, they have developed a polymer composite material that can heal itself when cracked. This paper summarizes the self-healing concept for polymeric composite materials and investigates fracture mechanics issues consequential to the development and optimization of this new class of materials. The self-healing material under investigation is an epoxy matrix composite, which incorporates a microencapsulated healing agent that is released upon crack intrusion. Polymerization of the healing agent is triggered by contact with an embedded catalyst. The effects of size and concentration of catalyst and microcapsules on fracture toughness and healing efficiency are investigated. In all cases the addition of microcapsules significantly toughens the neat epoxy. Once healed, the self-healing polymer recovers as much as 90% of its virgin fracture toughness.

Crack-healing phenomena have been discussed in the literature for several types of synthetic materials including glass, concrete, asphalt, and a range of polymers.4-15 While these previous works were successful in repairing or sealing cracks, the healing was not self-initiated and required some form of manual intervention (*e.g.* application of heat, solvents, or healing agents). Others have proposed a tube-delivery concept for self-repair
of corrosion damage in concrete and cracks in polymers. Albeit conceptually interesting, the introduction of large hollow tubes in a brittle matrix material cause stress concentrations that weaken the material and beneficial healing may be difficult to realize. In contrast, the microcapsule concept developed by White *et al.* is particularly elegant, practical, and promising for the healing of brittle thermosetting polymers. In this paper, they present a comprehensive experimental investigation of the correlative fracture and healing mechanisms of this self-healing system. Effects of microcapsule concentration, catalyst concentration, and healing time are studied with a view towards improving healing efficiency.

10. "Self-healing concrete with a micro-encapsulated healing agent" Michelle M. Pelletier Richard Brown , Arun Shukla and Arijit Bose Laboratory of Soft Colloids & Interfaces, Department of Chemical Engineering, University of Rhode Island, Kingston, RI, 02881, USA.

They have 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. Compressive strength is unaffected by the presence of capsules. 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 capsule-containing samples displayed ductility, in contrast to brittle failure in the control samples. They also show a significant reduction in corrosion. The flexural strength recovery, the improved toughness and the attenuation of corrosion make it a promising material for construction.

For preparation of microcapsule they introduce following procedure,

4.202mL of Span 85 and 2.116mL of polyethyleneglycol (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 E1. 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. Finally, E1 was added to this primary emulsion and stirred at 700rpm for 10 minutes at room temperature. The speed was reduced to 350 rpm at 63ºC and allowed to react for 4 hours. Microcapsules sizes varied from 40-800 microns.

This experiment was used to evaluate whether the material was able to recover some of its strength after acquiring some minor, microscale damage. First, the sample was loaded to incipient failure, indicated by the sharp decrease in the load-displacement curve. The samples were then left to heal for one week. During this time period, the solution that is released from the capsules has time to react with the calcium hydroxide to form the C-S-H, partially filling some of the cracks that have formed.

Strength recovery is reported as a percentage of the maximum strength reached after minor damage has been induced compared to the maximum strength in the initial test. The control samples had about 10-14% of its initial strength left after microscale damage had occurred. The samples containing the microcapsules had 20-26% recovered strength after the damage. This is indicative of the capsules rupturing where the cracks were initiated, partially healing them and providing more strength to the samples in the second test. Ultimately, this type of healing would be able to promote a longer life of the material since it is prolonging the time to failure. The 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. Their real ability is demonstrated in testing the flexural strength after inducing microcracks, where the presence of the microcapsules helps the material perform *at least* 10% better than the control samples.

The results for the capsule-containing samples showed a significant amount of corrosion inhibition compared to the control samples. With increased capsule loading (optimized for strength), more silicates can be deposited onto the wire to form a passive layer that could protect it for greater time. An ideal application for this system would be as an added aid for corrosion inhibition in an already protected structure.

11. “Self-healing Materials: Fundamentals, Design Strategies, and Applications” Edited by Swapan KumarGhosh Weinheim. (2009)

Here, in this paper, different types of healing processes are considered as self-healing in general. Currently, self-healing is only considered as the recovery of mechanical strength through crack healing. However, there are other examples where not only the cracks but also small pinholes can be filled and healed to have better performance. Thus, this review addresses recovery of different types of properties, of materials. Liquid active agents such as monomers, dyes, catalysts and hardeners containing microcapsules, hollow fibers, or channels are embedded into polymeric systems during its manufacturing stage. In the case of a crack, these reservoirs are ruptured and the reactive agents are poured into the cracks by capillary force where it solidifies in the presence of predispersed catalysts and heals the crack. The propagation of cracks is the major driving force of this process. On the other hand, it requires the stress from the crack to be relieved, which is a major drawback of this process. As this process does not need a manual or external intervention, it is autonomic. The following sections give an overview of different possibilities to explore this concept of designing self-healing materials.

Microcapsule-based self-healing approach has the major disadvantage of uncertainty in achieving complete and/or multiple healing as it has limited amount of healing agent and it is not known when the healing agent will be consumed entirely. Multiple healing is only feasible when excess healing agent is available in the matrix after the first healing has occurred. Thus, to achieve multiple healing in composite materials, another type of reservoir that might be able to deliver larger amount of liquid healing agent was developed by Dry and coworkers.

12. “Self-healing materials: a review” by Richard P. Wool Advance Article (January 2008)

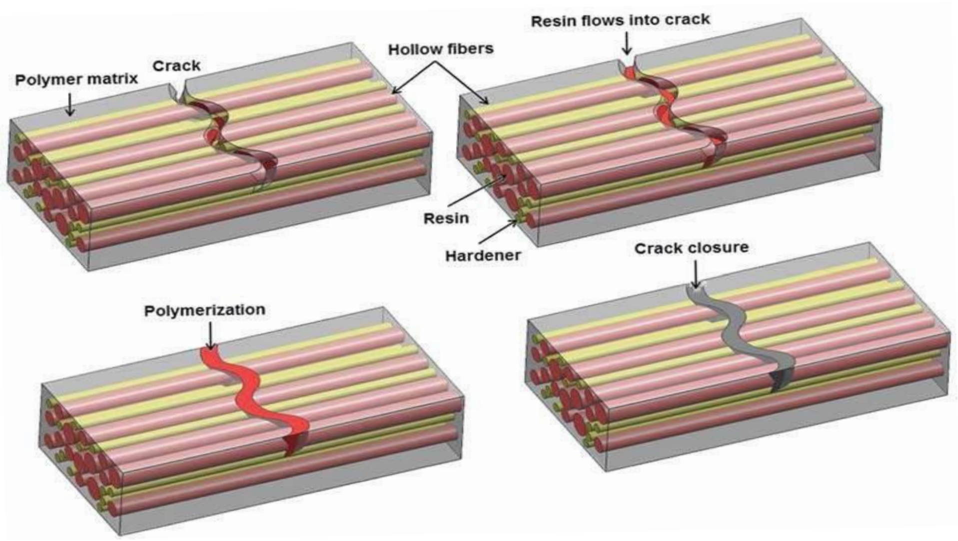
Self-healing materials are polymers, metals, ceramics and their composites that when damaged through thermal, mechanical, ballistic or other means have the ability to heal and restore the material to its original set of properties. Few materials intrinsically possess this ability, and the main topic of this review is the design for self-repair. This is a very valuable characteristic to design into a material since it effectively expands the lifetime use of the product and has desirable economic and human safety attributes. In this review, the current status of self-healing materials is examined in Section 1 of paper, which explores the history and evolution of several self-repair systems including nanobeamhealing elements, passive self-healing, autonomic self-healing and ballistic self-repair. Section 2 of paper examines self-healing mechanisms, which could be deployed in the design of these unusual materials and draws much information from the related field of polymer–polymer interfaces and crack healing. The relationship of material damage to material healing is examined in paper in Section 3 in a manner to provide an understanding of the kinetics and damage-reversal processes necessary to impart self-healing characteristics. In self-healing systems, there are transitions from hard-to-soft matter in ballistic impact and solvent bonding and conversely, soft-to-hard matter transitions in high rate yielding materials and shear-thickening fluids used in liquid armor. These transitions are examined in Section 4 in terms of a new theory of the glass transition and yielding, viz., the twinkling fractal theory of the hard-to-soft matter transition. Section 5 of this paper gives an overview of the most recent advances in the self-healing field, including the biomimetic microfluidic healing skins, and provides some prospective for the future design of self-healing materials. The biological analogy of self-healing materials would be the modification of living tissue and organisms to promote immortality, and many would agree that partial success in the form of expanded lifetime would be acceptable. Hopefully, the reader of this review is left with a sense of what-to-do and what-not-to-do when designing self-healing materials, perhaps not always as this author intended.

IV. Research Methodology

In development of self-repairing system the basic step is laying the profile of voids ducts with the help of void former material, so that this can be filled with resin and hardener. Resin is basically a benzene ring compound and hardener is diamine product. When the crack formation will took place in this region it will trigger the resin, and allow it to penetrate through the cracks. Propagation of crack through the duct will allow resin and hardener to mix with each other forming a curing or repairing compound which will get set into crack with repairing it.

Following are stepwise methodology of test conducted on specimen,

- Profile of duct is laid in crack prone area of structure.
- This duct consist the repair chemical most commonly Epon epoxy within it.
- Epon epoxy work as resin which is structurally similar to the continuous benzene ring generally named as Epichlorohydrin.
- Diamine is used as hardener which in contact with resin starts the process of curing under the presence of catalyst.
- Resin+Hardener under polymerization forms curing agent which repairs the concrete.
- Crack formation is trigger of the system which initiates the mixing and curing reaction.
- This curing agent has same cementations characteristics as that of mother concrete.



(Schematic representation of repairing system within specimen)

While developing and defining the test methodology following points was taken into the consideration,

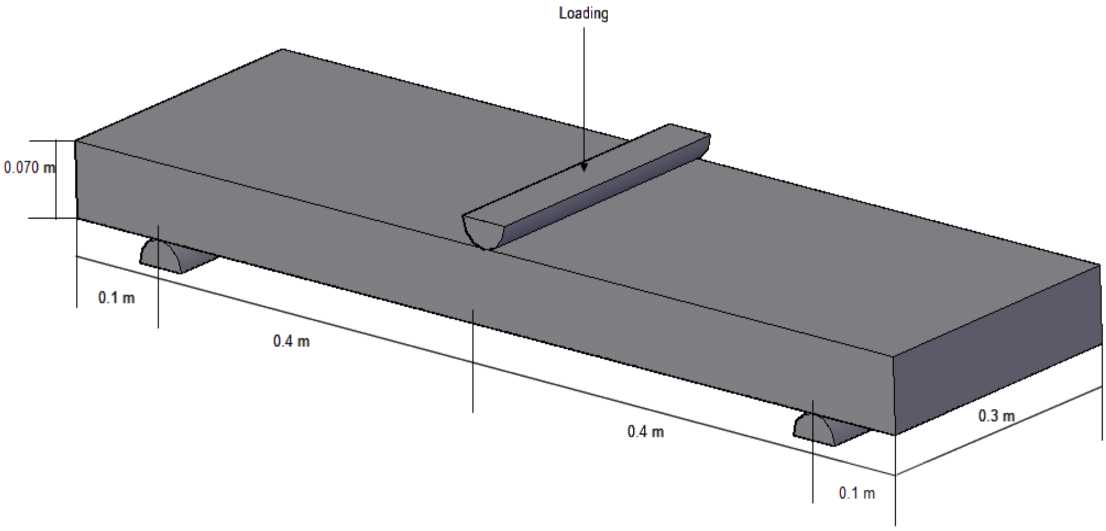
1) Test to be conducted
2) Selection of epoxy resin
3) Dimension of test specimen and mix design
4) Formation of duct (void former) and diameter of ducts
5) Profile of duct system
6) Position or arrangement of duct system
7) Arrangement and proportion of resin and hardener.

V. Proposed tests to be carried out on design model in laboratory

- Use of high pressure pumping of chemical can be useful in this case.

Test on specimen

To perform the laboratory testing the one point flexural test was selected, So that crack formation can be initiated in the central bottom part of specimen and accordingly the profile of void former and reinforcement can be laid.



Loading diagram of one point flexural system

Selection of epoxy resin

Following are some expected properties of chemicals before we start selection:

1. **pH values:** The pH values should be from 6.8 to 7.2. The chemicals should not be too alkaline or acidic because the mother concert and reinforcement should not affect.

2. **Compressive strength:** The repairing chemical should have enough compressive strength to match mother concrete.

3. **Viscosity:** The chemicals should have viscosity such that it should flow within 10 seconds to fill the cracks hence; the viscosity should be very high and will be calculated as the application of chemicals to repairing zone.

4. **Final setting time:** The repairing material should set immediately as soon as it release from tube. The final setting time should be more than 10 seconds.

5. **Temperature:** The temperature should be from 35° to 50° or natural temperature, etc.

In selection of chemicals in self-repairable concrete system main component i.e. resin and hardener were selected such that, it will get mixed together after formation of crack and will get set within crack with addition of sealing it. Some criteria for the selection of resin considered are,

a) The material should be able to repair different types and sizes of damages.
b) It should be economically viable.
c) It should be easily available in market.
d) While using the chemical it should not cause hazardous effects.
e) It should establish good quality assurance and reduce life cycle cost.
f) It should withstand different forces and dynamic loads.
g) It should have satisfactory properties like compressive strength, viscosity and pH.

pH value is such that it will not cause any corrosion to the reinforcement. Viscosity of both the chemical shall be such that it will seal the minor cracks like shrinkage or temperature cracks. Working temperature of both the solution shall be wide.

Different types of chemical or resins and hardeners are manufactured by different chemical manufacturing company in our country like MC Bauchemie, Pidilite, Suvarna Chemical, Krishna Chemicals and D. R. Coats and resins etc. From this we have selected epoxy and hardener which is making of D.R. Coats and resin, Tarapur, Mumbai.

Dimension of specimen and mix design

Size of specimen is such selected that we can lay the number of profile duct along the width of specimen in tension side of specimen. We found that selection of slab panel will be the ideal to conduct the test in desired path. For the same reason a slab panel of size 300mm x 70mm x 1000mm is selected. This size allowed us to provide number of duct closer to each other along the width. The profile of this duct was parallel to the length of specimen. When one point loading system applied on slab panel formation of crack will take place along the width of specimen. This will cause crack formation across duct filled with chemical and crack formation will take place. Sufficient cover for placing concrete was provided depending on minimum size of aggregate used.

Cross section of specimen with position of reinforcement and duct is as shown in figure,

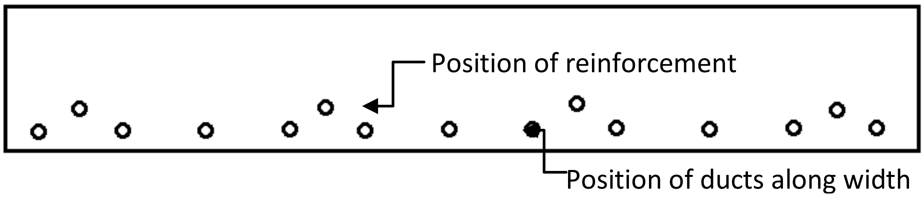


Fig. Position of void former and reinforcement in specimen

Void former and duct diameter

To provide duct system closer to each other and to the tension side a void former of polyurethane material was used. 6mm diameter of pipe was selected to carry out initial testing. Polyurethane is basically plastic material with has very smooth surface. Hence it was easy to remove the pipe from the specimen after initial setting of concrete. This void former are available from 2mm to 8mm ID. For our purpose of pilot test we have selected 6mm outer dia. polyurethane pipes.

Fig. Polyurethane pipe as void former 6mm outer diameter

Profile of duct system

As initially discussed profile of duct shall be laid such that it will be in tension zone or in crack prone area. Hence these ducts are provided along the length of specimen and orientation of duct was kept perpendicular to cracks. So that it will ensure the simultaneous release of resin and hardener and proper mixing of it with each other.

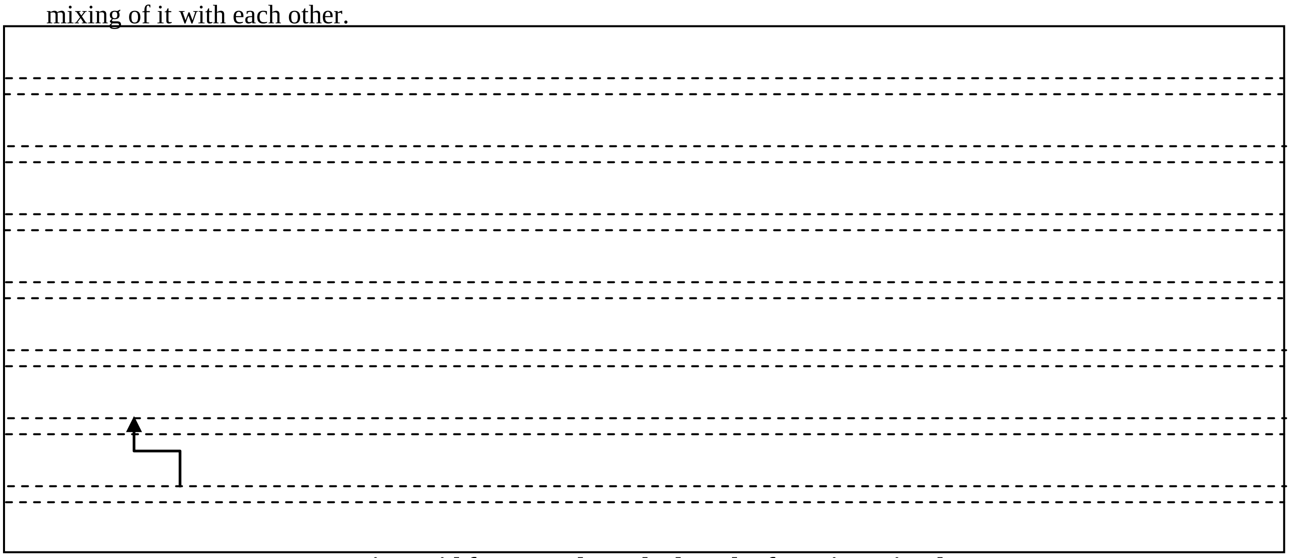


Fig. Void formers along the length of specimen in plan

Position and arrangement of duct system

While fixing with position of duct system to tension side along the crass section minimum aggregate size was taken into consideration. Clear cover to duct was kept as 12mm and there is reinforcement provided in between two successive ducts, so as to ensure proper concreting.

The clear cover to reinforcement was kept as 20mm. For slab 4 nos. of 6 mm dia. mild steel bars were used.

Fig. Shuttering for test specimen fitted with void formers

Arrangement and proportion of resin and hardener

In initial testing alternate ducts was filled with resin and hardner.

Epon epoxy solution were taken for this purpose is,
Resin – Dropoxy – 7250
Hardener – Dromide – 9340
(Make of D.R. Coats Ink and Resins)
This is high temperature and thermal shock epoxy.

Fig. Epoxy resin
(Dropoxy 7250)

Fig. Hardener
(Dromide 9340)

Some properties of it are as follows,

Viscosity 12000 cps @25 deg. C.
Sp. Gravity 1.4
Compressive strength upto 135 MPa
Tensile strength upto 50 MPa
Working temperature - 70 to 260 deg. C.

These solutions can remain as it is for 2 years if not come in contact with each other.

While feeling this solution in test specimens in first part ducts were filled with alternate resin and hardener and specimen was tested. In second part of all ducts of test specimens were filled with resin and hardener mixing together and observations was made

VI. Discussion and conclusion

The aim of this project work was to find out the epoxy resin or chemicals in our country which is suitable to our environment and construction condition. Also the technique to provide this chemical resins in the actual structure by ducting and to check the repairing of cracks automatically with this resins and hardners. For the same reason pilot test will be carried out on the slab specimen with different variation in filling technique and mixing technique of resins .

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