Experimental Study on Self Healing Concrete using Micro Encapsulation

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Abstract— **Recent studies in the literature have demonstrated the ability of self-healing process to be effective in enhancing the overall life of concrete. Healing at an initial phase of crack propagation increases durability .The concept of microcapsule healing is based on the healing agent being encapsulated and embedded in concrete .The project objective is to synthesize sodium silicate microcapsule (sodium silicate core with polyurethane shell) and to embed it in concrete and also to study the behavior of microcapsules in concrete to prove it to be worthy in healing cracks with the support of experiments performed. The microcapsules were synthesized using in-situ polymerization as an oil-in-water emulsion. When a crack propagates and reaches the microcapsule, the capsule breaks and sodium silicate which is present in the microcapsule as a core material is released into the crack to heal it. Sodium silicate microcapsules were added to concrete at 2% volume. Samples were tested at an initial stage using ultrasonic pulse velocity(UPV) test and retested after being stressed to initiate cracks in a third point bending system and also tested after 7, 14 days to witness the self-healing nature of the concrete. It was found that the addition of microcapsules had only negligible impact in strength aspect but it played a major role in improving durability property.**

Keywords— Sodium silicate, Micro capsule, polyurethane.

1. INTRODUCTION

Concrete is the most widely used construction material because of its high compressive strength and relatively low cost. It has desirable engineering properties that it can be moulded into any shape. But many concrete structures suffer from serious deterioration over time. The adverse property of concrete is its sensitivity to crack formation as a consequence of its limited tensile strength. Thus inspection and maintenance techniques for concrete structures have become the focus of increasing attention. However, the implementation of continuous inspection and maintenance is difficult, especially in the case of large-scale concrete structures, owing to the considerable amount of labour and funds required. The need for the development of concrete with high sustainability and durability is as important as the need for high strength concretes.Concrete is a brittle material which has very high compressive strength. Since concrete is weak in tension, even a hair line crack may propagate to a greater extent, thus reducing the durability of the structure. Therefore healing the cracks at an initial phase tend to increase the durability of the structure. Micro cracks often develop in cementitious composite during the hydration of cementitious materials or as a result of mechanical loadings, environmental loadings and volumetric instability. Once micro cracks have formed within concrete, they are extremely difficult to detect and repair by conventional methods. Over time, they will lead to significant cracking and spalling of concrete and subsequent reduction in the strength, serviceability, and aesthetics of the structure moreover, the detection of such micro cracks in the built up concrete structures is a tedious process. The best way is to incorporate supplementary cementitious products during design and casting of concrete structures which on later course acts on the purpose of repairing those cracks. Another solution for this problem involves the use of a new method known as “self-healing concrete.” Self-healing in concrete can be defined as the ability of concrete to autonomously heal cracks that develop throughout its structure. The concept of microcapsule healing is based on a healing agent being encapsulated and embedded in the concrete. When a micro crack, originating from internal stress or a physical damage, propagates through the coating, the microcapsules rupture and release healing agents which then start to react, forming a polymer network, and thus filling the crack.

2. SELF HEALING APPROACHES IN CONCRETE

Self healing can be defined as the ability of the concrete to heal cracks automatically.The development of self-healing materials is a relatively new area of research and there are Maintaining the Integrity of the Specifications numerous methods and processes available for self-healing cracks within damaged concrete. Self healing includes both the natural ability of concrete to heal cracks over time (autogenic) and artificial means of crack repair that are man-made inclusions (autonomic).

2.1 Microcapsule Based Self Healing

The microencapsulation approach is by far the most studied self-healing concept in recent years. This method is similar in design to the hollow tube approach. Monomer is encapsulated and embedded within the polymer. When the Cracks form in the matrix, it ruptures the microcapsules releasing the healing agent into the crack plane through capillary action. The healing fluid contacts the catalyst, which is randomly distributed in the matrix and triggers the polymerization reaction that helps to heal the damage by bonding the crack surfaces closed. There are two main aspects to consider with regard to this approach, namely, the encapsulation method and the healing agent that is encapsulated. Microencapsulation is done to protect either the healing agent or the catalyst, or both. The selection and manufacturing of effective self-healing microcapsules are the first step towards a successful application of this concept. The resulting microcapsules need to possess sufficient strength to remain intact during processing of the polymer matrix, rupture (rather than de-bond) in the event of the crack, capable of releasing the healing agent or catalyst into the crack, and have minimal adverse affects on the properties of the concrete. Although these methods are reliable and consistent, crack propagation plays a large role on its healing effectiveness. In this approach sodium silicate and Dicyclopentadiene(DCPD) are used as healing agents mostly. Micro-encapsulated sodium silicate healing agents with urea formaldehyde on the outer core are directly embedded into a concrete matrix. When cracks begin to form in the concrete, the capsules rupture and release the healing agent into the adjacent areas. The sodium silicate reacts with the calcium hydroxide naturally present in the concrete to form a calcium-silica-hydrate product to heal the cracks and block the pores in the concrete. The chemical reaction creates a gel-like material that hardens in about one week. The special feature of this material is that it can have a localized and targeted release of the healing agent only in the areas that really need it. When the Cracks form in the concrete it ruptures the microcapsules releasing the healing agent into the crack plane through capillary action.So sodium silicate microencapsulation was chosen.

3. PREPARATION OF SODIUM SILICATE MICROCAPSULES

The healing agent used as a core material in the microcapsules in this study is sodium silicate (Na_2O_3Si). It is also known as liquid glass. Sodium silicate in solid or aqueous solution is generally used in concrete applications for reducing its porosity. When sodium silicate is added to concrete, a chemical reaction occurs with the excess of $Ca(OH)_2$, which is already present in concrete and thus the concrete permanently binds with the silicates at the surface. Thus sodium silicate is a great sealer as well as a great water-repellent.

Sodium silicate reacts with calcium hydroxide, which is a product of cement hydration and produces a calcium-silica-hydrate gel, known as (C-S-H) gel. The formed C-S-H gel will act as a binder and healer in cracks and pores.The healing agent sodium silicate is encapsulated and embedded into the concrete. When a crack propagates and reaches the microcapsule, the shell of the capsule breaks and sodium silicate which is present in the microcapsule as a core material is released and reacting with calcium hydroxide forming C-S-H gel.

4. RESULT AND DISCUSSION

The tests that were done on microcapsules for testing its performance include compression test, UPV test, rebound hammer and bending test. 6 cubes were subjected to compression testing at an initial stage to find the ultimate failure load and another 5 cubes were cracked to the point of incipient failure and their healing efficiency were estimated after 14 days using compression testing. Bending test was done on the 5 cubes and 6 prisms to induce cracks. UPV test was done on 6 prisms and 5 cubes. It was done before loading, after inducing cracks and after 7 and 14 days of healing. Rebound hammer test was done initially on 6 cubes to find the correlation. It was then done on 6 prisms and 5 cubes to estimate compressive strength.

Tests on Cubes

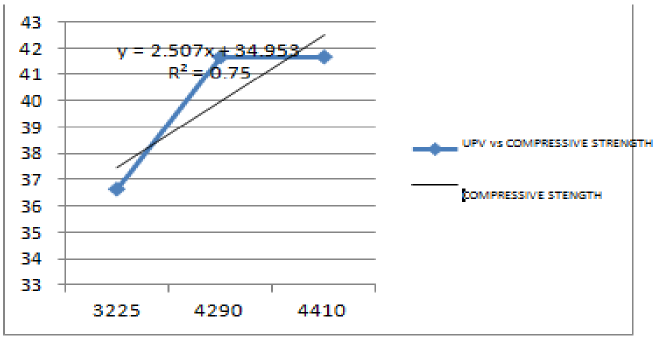
Rebound hammer was conducted on these cubes at 3 points on two opposite faces. These cubes were finally tested using compression testing machine and the ultimate compressive strength of these cubes were found.

Average compressive strength of the cubes (control specimen) = 39.967 Mpa

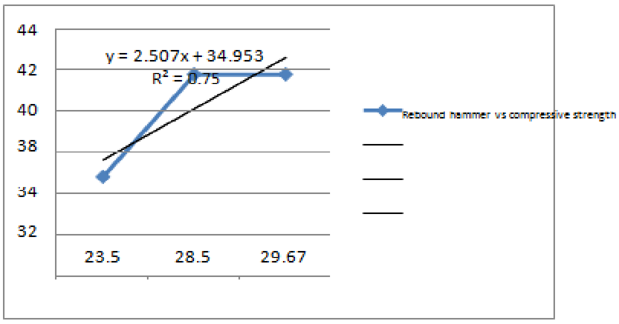
Average compressive strength of the cubes (microcapsule specimen) = 39.940 Mpa

From these results it could be identified that there was not much difference in strength due to the embedment of microcapsules.

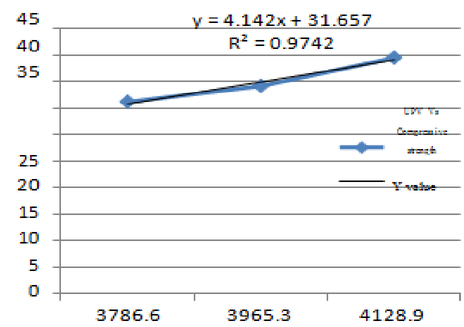
UPV and rebound hammer tests were done on these cubes at an initial phase to find correlation between these values and the compression strength values.



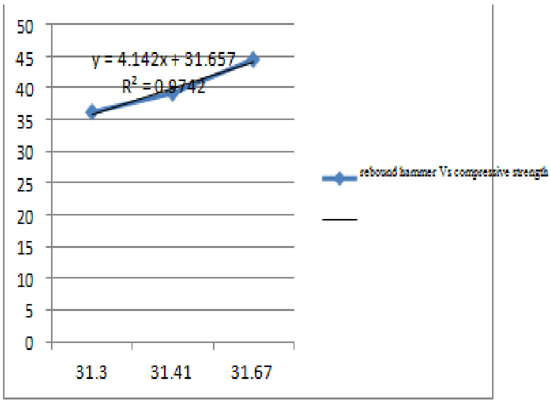
Graph1:UPV Vs compression strength for control specimen



Graph 2 : Rebound Hammer Vs Compressive Strength For Control Specimen



Graph 3: UPV Vs compressive strength for microcapsule specimen



Graph 4 : Rebound Hammer Vs compressive strength for microcapsule specimen

TESTS ON PRISM

Four prisms without microcapsule as control specimen and three prisms with microcapsules were cast and cured for 28 days.

REBOUND HAMMER TEST

Non-destructive compression test was done using rebound hammer at three points in the front face (F1,F2,F3) of the prism and three points on the rear side(R1,R2,R3).
compressive strength of the prisms (control specimen)=21.527Mpa
Average compressive strength of the prisms (microcapsule specimen)=20Mpa
UPV test was then conducted on the prisms at three points on the front and rear face of the prism.

	F1	F2	F3
R1	-127.8	1988.96	1578.26
R2	667.43	55.20	211.54
R3	-216.90	1441.74	62.77

Table 1: Difference In UPV Values Before And After Loading

The cracks were formed and the specimens were then left to be healed. To check if the healing has occurred in the specimens, they were tested on 7th and 14th day after initiating cracks. The average healing values after 7 and 14 days for the control specimen and the microcapsule specimen are given below

	% HEALING AFTER 7 DAYS	% HEALING AFTER 14 DAYS
Control specimen	-0.181	5.102
Microcapsule specimen	4.921	9.447
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Table 2: Average Healing Values After 7 And 14 Days For The Control Specimen Andthe Microcapsule Specimen

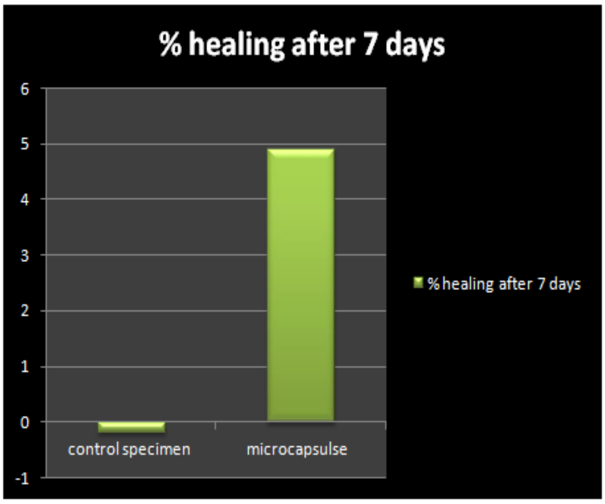

Fig 1. Percentage Healing After 7 Days

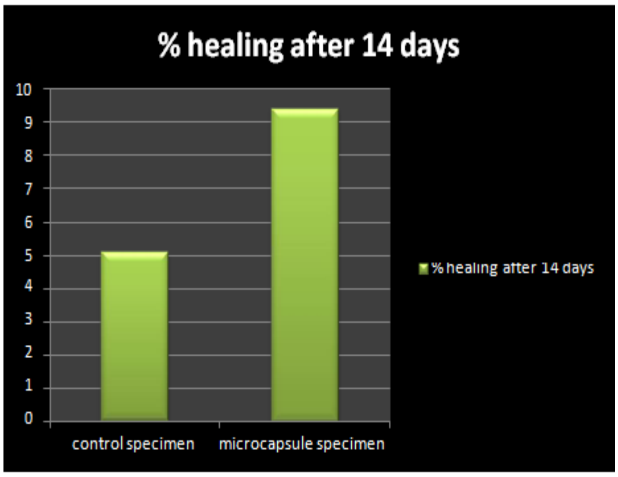

Fig 2. Percentage Healing After 14 Days

CONCLUSION

- The sodium silicate microcapsules were synthesized by in situ polymerization
- The sizes of the microcapsules formed were in the range of 2-5 microns
- The addition of sodium silicate microcapsules had negligible effect on the strength of concrete after 28 day curing
- The specimens with microcapsules had healed to 4.921% after 7 days and to an average of 9.447% after 14 days
- The specimens showed only minimum efficiency for concrete with 2% volume of microcapsules
- The efficiency can be increased with higher volume of microcapsules since 2% would have been sufficient only to fill the air voids in concrete
- The control specimens had increase in strength of 24.95% whereas sodium silicate microcapsule specimens had an increase of 254.60%. Therefore, the healing nature was thus confirmed

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