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Self-Healing Concrete Test Method and Experimental Procedure Conducted on Grout Specimens

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Abstract: The concept of self-healing concrete emanated from one of the most prestigious biological properties which is to naturally proceed healing performance when any damage appears and regenerating the functions. Thus, by relating that mechanism in engineering with the common phenomenon of crack formation, this concept has been studied and evaluated over the past years where Self-healing concrete was defined as the ability of cementitious composites to reduce or completely heal a crack width autogenously or autonomously upon damage. Therefore, test method and experimental procedure are conducted to ensure the efficiency of the mechanical properties and performances of the concrete, and also to help in a case of a research work or project; gathering some necessary information or data to apply adequately on a proposed hypothesis or work because the success of experimental research usually confirms that the change observed in the variable under study is solely based on the manipulation of the independent variable. In this paper, the emphasis is highlighted on test method and experimental procedure of self-healing concrete conducted on grout (W), commercial grout with 10% expansion agent (CCSA) and research grout with addition of expansion agent (WCSA) to evaluate its mechanical properties and performances.
Keywords: Self-healing, autogenous, autonomous, grout test method.

I. INTRODUCTION

This idea of self-healing concrete was inspired from the natural phenomenon by organisms. Damaged skin of human body and animals can selfheal [1, 2]. Therefore, looking at how the organism of human beings naturally proceed self-healing after skin damage or any other similar affliction, cement-based materials have the same mechanism of self-healing. In a general perspective for cementitious composites, this term refers to minimizing the crack width or to completely heal and repair of damage in cement-based materials. Hyde and Smith [3], [4] investigated this self-healing phenomenon at the end of the 19th century. Glanville [5] gave a more systematic analysis of healing phenomena, dating back to 1926. At this time, there was already a distinction made between self-healing and self-sealing.

II. MECHANISIM OF SELF-HEALING

Several approaches have been applied during the past 20 years to enhance self-healing materials in order to increase the lifetime and the enduring strength of concrete and self-healing leads to partial or complete crack-closing which ameliorates the durability, permeability and likely the mechanical properties.

In general, the self-healing mechanism can be subdivided into two different classes: autonomic or autonomous and nonautonomous [6].

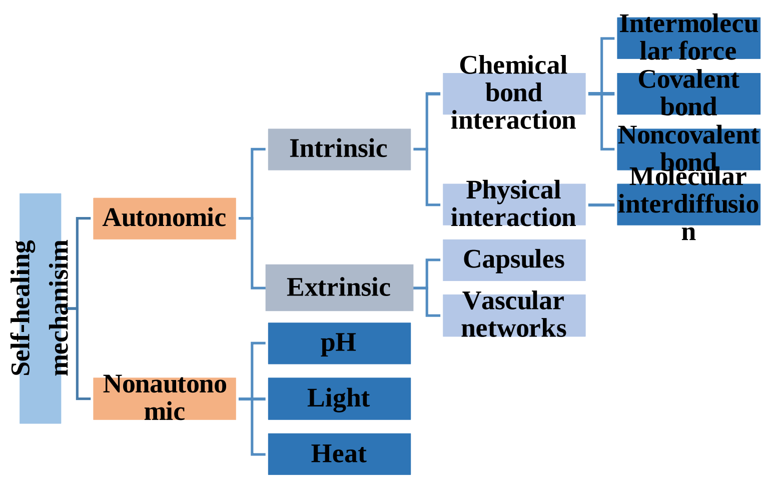

Fig 1 Flowchart representing the classification of self-healing systems. [7]

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III. AUTOGENOUS AND AUTONOMOUS SELF-HEALING

Given adequate conditions to cement based materials, they can fill the cracks with hydrated binders, crystalline or expansive products. This mechanism is called “Autogenous self-healing”. The crystallization of calcium carbonate within the crack in the primary process in autogenous self-healing of matured concrete [8]. And by realizing that without external stimuli, cement based materials are able to seal or heal the cracks, several researchers tried to develop a mechanism called “Autonomous self-healing”. It’s the purposeful designing and addition of engineered materials into cement-based materials to “heal” itself in the event of cracking.

A. Autogenous Self-Healing

The definition given to autogenous self-healing is the intrinsic healing method in concrete due to its composition of various cementitious components in the mixture. This method is dependent on the properties that make up the mixture itself. The basic phenomenon determining partial or total self-closure of cracks and implicitly, and partial recovery of initial durability and physical–mechanical performances of the composites.

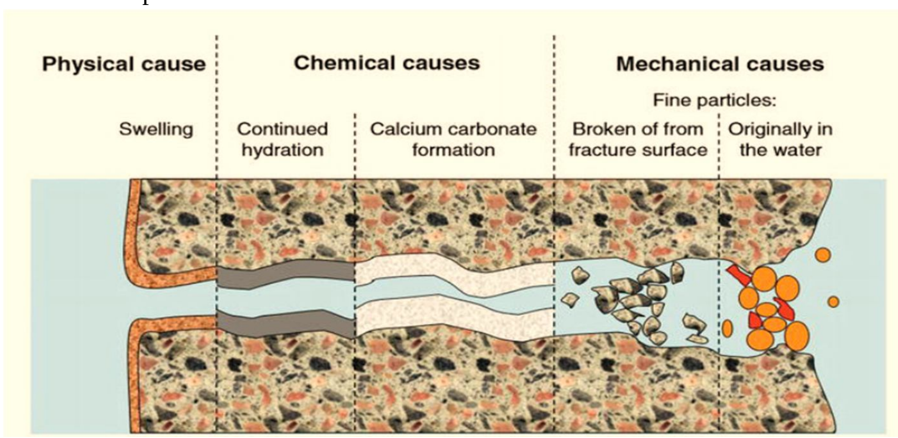

Fig 2 Main mechanisms producing autogenous self-healing of cementitious materials. Reproduced with permission. [9]

B. Autonomous Self-healing

Autonomic self-healing is considered as an artificial healing process which follows a deliberately accelerated artificial route in material damage repair. It relies on embedding unconventional engineered additions in the matrix to provide self-healing function. This healing method can be accomplished by chemical and biological. Damage in the material is important to trigger the healing process [10, 11]; actuation (triggering actions), transport of healing products into fractured zone and chemical repair.

Autonomous self-healing method can be subdivided into various main categories such as microcapsules [12, 13], self-healing using bacteria [14, 15], and hollow fibers and shape memory materials [16, 17]. To avoid unfortunate premature reaction while mixing cement components, healing agents, bacteria and chemical components can be put inside a protective casing. The encapsulation is shown in Fig 4.

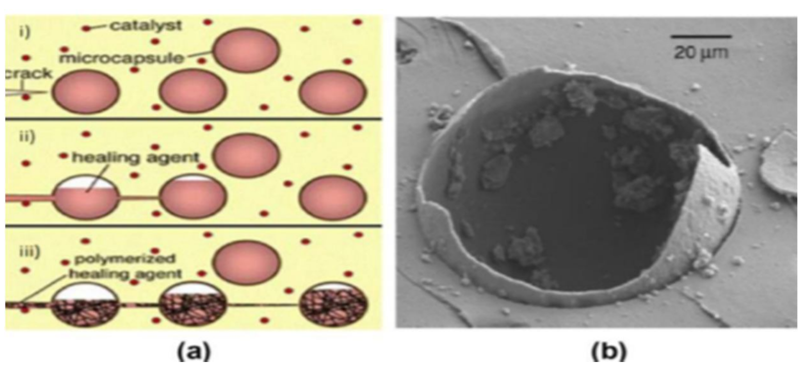

Fig 3 (a) Basic method of the microcapsule approach: (i) cracks form in the matrix; (ii) the crack ruptures the microcapsules, releasing the healing agent into the crack plane through capillary action; (iii) the healing agent contacts the catalyst, triggering polymerization thus ensuring the closure of the near-by cracks and (b) ESEM image showing a ruptured microcapsule [9]

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One of the preferred technique used for direct internal delivery of healing agents at the location of damage allowing in situ repair is encapsulation which relies on two main approaches; discrete and continuous. The main difference lies on the mechanism used to store the healing agent and thus dictates the extension of the damage that can be healed, the repeatability of healing, and the recovery rate for each approach.

The basic principle of strategy is healing by incorporated healing functionality or reactive constituents into capsules followed by chemical reactions. These reactions take place by various mechanisms including ring opening metathesis polymerization (ROMP) [18], cycloreversion [19], cycloaddition [20], cross-linking reactions [21], or a mechanochemical catalytic activation [22].

IV. TEST METHOD AND EXPERIMENTAL PROCEDURE

In this study, the research grout specimen was tested to check its mechanical properties. Furthermore, the self-healing phenomenon of both the commercial and research grout was investigated. The samples were prepared using 2 different grouts: one made with commercial cement and the other made with research cement. The 2 types of specimens were tested to check their self-healing abilities. For the self-healing specimen 10% of CSA by mass of the grout was added.

A. Preparation of Grout Specimen

A total of 33 grout specimens were made for this study. The specimen were divided into 3 groups. One group had the research grout only (W), the second had commercial grout with 10% expansion agent (CCSA), and last group was the research grout with the addition of expansion agent (WCSA).

The specimens were prepared in the laboratory. The cement, CSA and water were added into the blow of the mixer, careful to avoid loss of water or cement. The mixer was set to medium then high speed to achieve a homogenous mixture.

The molds of the specimen cleaned and oiled before casting of the grout. The grout was placed into the mold in 2 layers. The first layer was added then vibrated on a vibrating table for 120s. Afterwards, the second layer was added making sure to add a surplus of grout then leveling it and vibrating it again (ISO 679: 2009). The specimen were covered by a plastic sheet to maintain moisture for 24 hours as shown in Fig 4. Afterwards, the specimen were left to cure in the curing fridge for 28 days at room temperature (20±5°).

After the 28-day curing, the grout was tested in compression and flexure (bending) to initiate cracks for self-healing. The specimen were loaded to 75% of the ultimate strength. The ultimate strength was determined by loading some specimen until failure. After the 75% preloading for crack initiation, the specimen were left to cure in tap water and saturated $Ca(OH)_2$ solution for 20 and 35 days and tested to determine the self-healing efficiency in compression, Ultrasonic Pulse Velocity test, sleeve tensile testing and Scanning Electron Microscope (SEM) analysis.

Fig 4 Curing of Specimen [23]

B. Bending Test

The bending test is a method of testing materials for their bending strength and other important properties. Destructive materials testing is used for plastics, fiber-reinforced plastics (FRP), metals and ceramic materials [24]. Bending tests are similar in their sequence.

The 12 rectangular specimen of dimension 40x40x160mm were cast for the bending test. Three-point bending is used to test the specimens in bending. The specimens are considered as simple supported beams and the load is applied using a WREN RC158A 15ton Manual Hydraulic jack. A load cell was used to measure the load applied to the specimen. A metallic half-globe was used on top of a metallic stick to distribute the load uniformly at the middle point. Fig 5 shows the setup of the testing apparatus.

Fig 5. 3-Point Bending Test Setup [23]

The load was manually applied to the center by the loading nose producing three-point bending at a 50N/s. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test. These parameters are based on the test specimen thickness and are defined differently by ASTM and ISO. For ISO 178, which we used as the standard for this test, the test stopped when the specimen breaks. If the specimen does not break, the test will continue as far as possible and the stress at 3.5% (conventional deflection) is reported. The data is recorded using a data logger connected to the load cell. After failure, the specimen were used for the compression test.

C. Compression Test

Compression test is used to determine a material's behavior under applied crushing loads, and are typically conducted by applying compressive pressure to a test specimen (usually of either a cuboid or cylindrical geometry) using platens or specialized fixtures on a universal testing machine [25, 26].

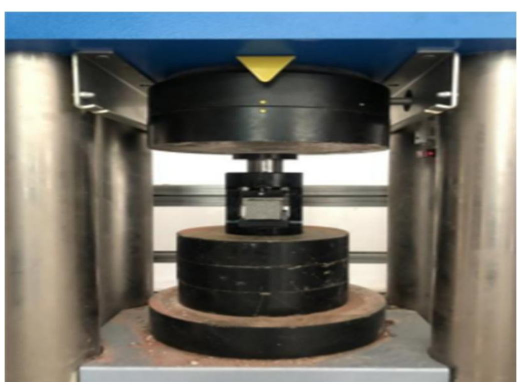

Fig 6 Compression Testing [23]

The compressive test loads were applied using the Servotronic YIMC109N compression testing machine. The applied load was monitored using the machine gauge. The compression test of grout was done by means of the specimen of dimension 40x40x80mm. These were taken from the bending test. The research grout specimen were loaded until failure whereas the self-healing specimen were loaded to 60%, 70%, 75% and 80% of their ultimate strength to initiate cracks in the specimen. The ultimate compression load was determined by loading some specimen to failure. The loading rate was 2.4kN/s as per GB/T 17671-2009.The applied load was monitored using the by the machine pressure gauge. After the first curing stage, all tests were conducted until failure.

The procedure used for concrete cube compression testing was as follows: The specimen were removed after the 28-day curing time and any excess water was wiped out from the surface of the specimen. The dimensions of the specimen were then measure to the nearest 0.2mm. The bearing surface of the testing machine was cleaned and the specimen was placed and aligned on the base plate of the machine. The movable portion of the machine was rotated so that it touched the top surface of the specimen such that the load was applied to the opposite sides of the cube as shown in fig 6 The load was then gradually applied to both sides of the cube continuously and without shock till the specimen failed.

D. Ultrasonic Pulse Velocity Test

Ultrasonic pulse velocity (UPV) test is used to check the quality of concrete also defects within concrete by passing electronic waves through the concrete [27].

The device used was the Huangdongshan Electronics CTS 25 Ultrasonic Pulse Velocity Tester. To check the soundness of the specimen, an ultrasonic pulse velocity test was carried out. This test emits ultrasonic wave pulses (50 to 54 kHz) from one transducer and measures the time (T) it takes for these waves to be received by the other transducer on the other end. The transducers are in contact with the surface of the member under test. The pulse velocity can be calculated by V=L/T where the path length L, is the distance between the two transducers and time is of travel. The set-up is shown in Fig 7. The specimen pulse velocity was checked. Thereafter, the specimen were loaded to 60% and 80% of their ultimate load and the checked again to see if there would be any changes in their pulse velocities.

Fig 7 Set up of UPV test. [23]

E. Scanning Electron Microscope (SEM)

Scanning Electron Microscopy, or SEM analysis, provides high-resolution imaging useful for evaluating various materials for surface fractures, flaws, contaminants or corrosion. Performing a visual analysis of a surface using scanning electron microscopy contributes to the identification of contaminates or unknown particles, the cause of failure and interactions between materials [28].

The specimen were scanned using the Scanning Electron Microscope (SEM) to ascertain if the self-healing phenomenon occurred. There were a total of 8 specimen scanned: CW35, CWCSA35, CC35, CCCSA35, WW35, WWCSA35, WC35 and WCCSA35. The SEM test was conducted on the specimens with and without the self-healing materials, and on the specimen in the 2 curing conditions.

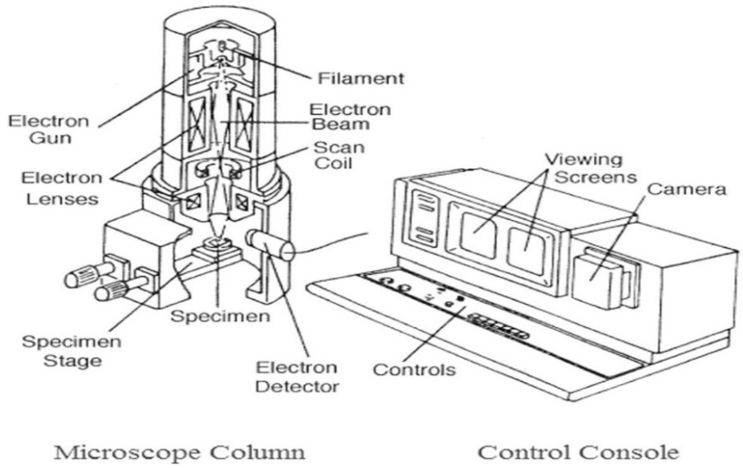

Fig 8 two major parts of the SEM, the electron column, and the electronics console [28]

V. CONCLUSION

To evaluate the mechanical properties of the grout and to study the self-healing phenomenon, the specimen preparation, mixing and curing have been explained. A total of 30 grout specimen were made for this study. The specimen were divided into 3 groups. One group was with the research grout (W), only, the second group was the research grout with the addition of expansion agent (WCSA) and the last group was commercial grout with 10% expansion agent (CCSA), For the determination of mechanical properties, 15 rectangular specimen of dimension 40x40x160mm were cast for the bending test, with three-point bending as the testing method. After the bending test, these specimens were then used for the compression tests.

The self-healing study specimen were precracked then left to cure for 20 and 35 days, and then were tested by compression, UPV and SEM to check the self-healing. The specimen preparation and tests that have been outlined are the bending, compression, UPV and SEM tests. These procedures will determine the mechanical properties of the grout and aid this study's further research into the self-healing phenomenon.

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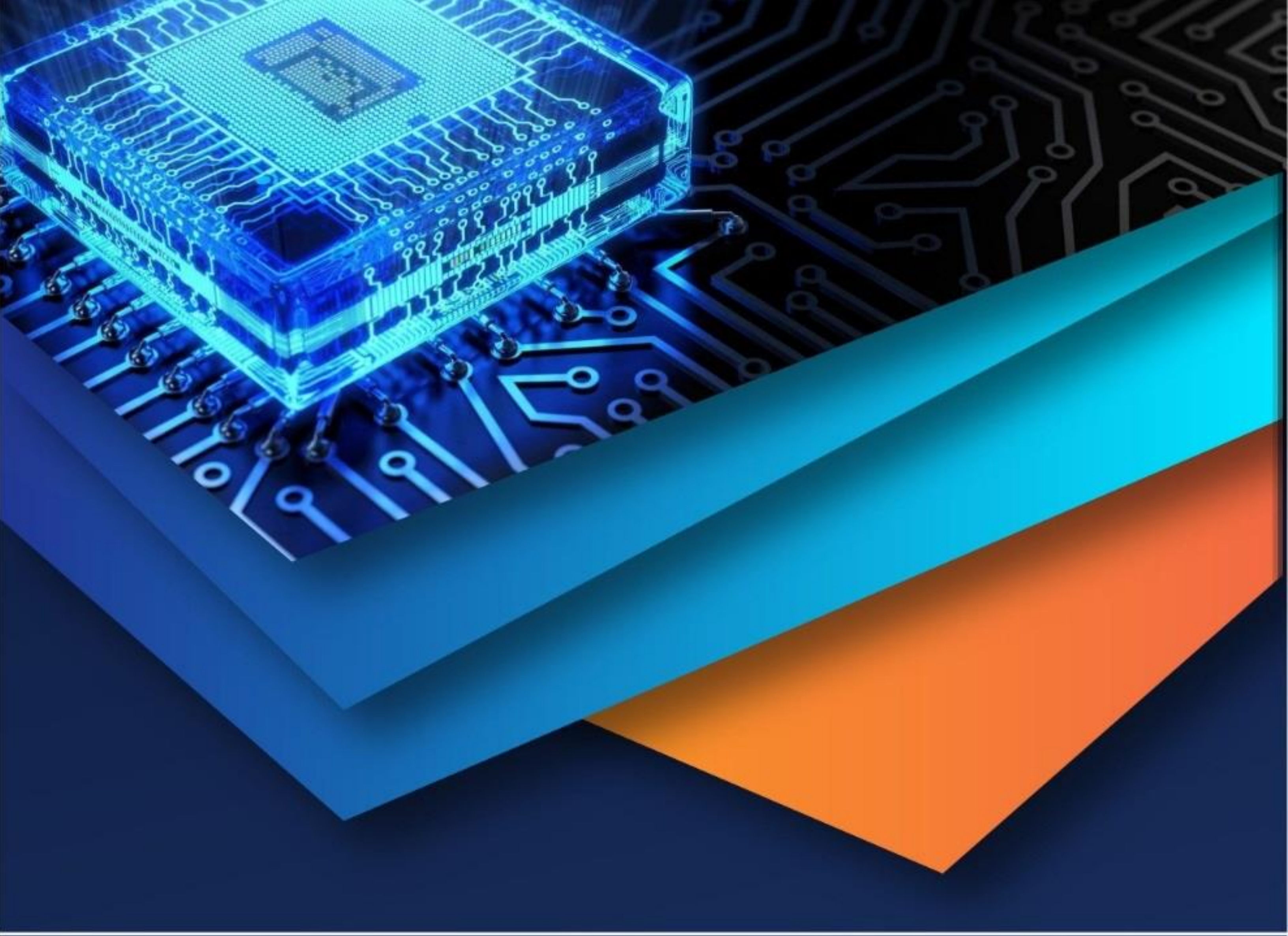

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