Improvement Properties of Self -Healing Concrete by Using Bacteria

Z M Hussein 1*, A H Abedali 1 and A S Ahmead 2

1 Highway and Transportation Engineering Department, Collage of Engineering, Mustansiriya University, Iraq.
2 Food science Department, College of Agricultural Engineering Science, Baghdad University, Iraq.
*Corresponding author E-Mail: zainabali@uomustansiriyah.edu.iq

Abstract. The aim of this investigation, self-healing of cracks in concrete by using named Bacillus Subtilis bacteria isolated from agricultural soils and dry soil. Four concrete mixes include, one plain mix without bacteria, other mixes containing a different concentrations of bacteria $10^3$, $10^6$ and $10^9$ cell/ml respectively were prepared. Hardened properties of concrete water absorption, ultrasonic plus velocity, and compressive strength at 7, 28, 60 and 90 days. Also concrete specimens applied to load 10% of compressive strength at 28 days were studied. The result indicate there is decrease in water absorption of (15-38)%, as well as the decrease in the concrete specimens of loading 10% of compressive strength of (23-41)%, relative to control concrete. Increase in compressive resistance of concretes specimens of (6- 20)%, (6-17)%, (8-22)% and (7-20)% for ages 7, 28, 60 and 90 days respectively, concrete specimens loaded by 10% of compressive strength, increased by (25-34%) and (34-39%) for 60 and 90 days relative to control concrete. It was observed that the UPV test of concrete specimens was increased. Scanning Electron Micrographic gave an increased in density, deposition of calcite carbonates in the voids and closure of the crack by precipitation of calcium carbonate layers was observed.

Key words: Bacteria concrete, self-healing concrete, bio-concrete, Micro-crack.

1. Introduction

Concrete is one of the most commonly used mixture materials, the concrete mixture suffers from many problems that lead to the occurrence of a micro-cracks or in motion cracks propagated quickly to create different types of failure may not be processed. The main defects of the concrete are the appearance of micro-crack resulting from relatively low tensile strength due to high external loads, high tensile stresses due to irregular deflection, restrain of shrinkage, plastic deformation and temperature variations. Thus affecting the durability of concrete. The appearance of micro- cracks has a wider impact than other cracks that make concrete more porosity and permeable to enter liquids and chemicals such as sulphates and chlorides for long periods that lead to the fracture and damage of concrete as well as the oxidation of reinforce steel and so, affect the durability of concrete [1].

However, most approach treatment concrete is conventional methods because have relied on main materials which are epoxy materials, acrylic resins, and polymers. These materials are not compatible to repair concrete for coefficient of thermal expansion and their produce production leads to pollution to the
environment [2]. In order to overcome the defects of conventional methods of repair concrete, it can be used self-healing ability as effective material since it involves urea of producing bacteria. The bacteria play an important role to grow inside the concrete micro-structure which assists in mineralization of calcium carbonate, by through hydrolyzing urea existing in the surrounding environment. Consequently, carbon dioxide of urea emits with collecting calcium ions and deposit calcium carbonate in the formation of calcite.

Bio-Concrete or Self-Healing Concrete have a new type of concrete developed by researchers called Bio-Concrete or Self-Healing Concrete, can be used to treat the inanition treatment cracks by adding a special type of bacteria to a concrete mixture that has the ability to produce and precipitate of calcium limestone (calcium carbonate) will have the ability to repair and treatment hair cracks [1].

The first study was conducted on calcium deposition properties in 1995 by researcher Gollaspuid and others in 1995. Researchers used a technique to reduce porosity and soil permeability by injecting bacteria [3]. Also, several studies were also conducted to develop different methods of using bacteria to improve properties concrete and repair cracks Ravindranatha, N. Kannan, Likhit [4], R A. B. Depaa and T. Felix Kala [5], Chithra P, BaiShibi Varghes [6] and Abhishek Thakur, Akshay Phogat and Khushpreet Singh [7]. Locally, a study was conducted to treatment concrete cracks by using bacteria (Bacillus Subtilis), silica powder and sodium chloride. Silica, chloric acid and bacteria were also used for the treatment of cracks in by making cracks in the concrete with a width of 1, 2 mm. Ultrasonic plus velocity and the scanning electron microscopy were examined. The researchers concluded that the crack with the width of the 1 mm was better and easier than the width of the 2 mm and using the silica and bacterial treatment material gave the best results [8].

The research idea involves adding different concentrations of the prepared solution bacteria type Bacillus Subtilis (B.S), adding to the concrete mixture, conducting the water absorption tests, compressive strength, ultrasonic plus velocity test comparing of the control specimens. Also, concrete specimens at the age of 28 days was applied load 10% of the compressive strength of the specimens examined for the purpose of healing micro-cracks in the concrete specimens to and this return to curing and tested with ages 60 and 90 days to demonstration the effect of the effectiveness of bacteria in concrete cracks self-healing.

2. **Research objectives**

The main objectives of present research work are:

1. Studying the effect of various concentration of Bacillus Subtilis bacteria on mechanical properties of concrete with different age.
2. Predicted self-healing of micro-crack of micro structure of concrete.

3. **Experimental work**

In this research, ordinary Portland cement type (I) was used. The tests result demonstrate that the physical and chemical properties of cement used conform with Iraq standards No.5/1984 [9]. Natural sand passing sieve No. 4.75 mm was used. The physical properties for sieve analysis shows that the sand used is combatable with the Iraqi Standard No. 45/1984 [10]. Nominal maximum size of 14 mm of natural crushed coarse aggregate was used. The sulphate content and grading of the coarse aggregate satisfy the requests for Iraqi Standard (No. 45/1984) [10]. Condensed Silica fume (SF) is a highly active Pozzolanic materials. It is a by-product from the produce of silicon or ferro- silicon metal. Tables 1 and 2 demonstrate the physical and chemical properties of condensed silica fume utilize in this study as partial replacement of cement. The results prove that SF utilized meets the requirements of ASTM C1240 – 06 [11]. The tap water used in mixing and curing of concrete was potable water from the water supply network. Also, High Range Water-
Reducing Admixture (HRWRA) with a commercial Sika-Viscocrete-5930 was used. It is the third generation of superplasticizer meets the satisfies of ASTM C494M/04 types F [12]. The mechanism of HRWRA contributes to flow able concrete with to decrease the of w/c ratio in the mixture. Table 3 specifies the technical explanation of the hydrous solution of superplasticizer utilized during this study.

Table 1. Physical properties of condensed silica fume

| Physical properties                                      | Results, SF | ASTM C, 1240-05 Limits |
|---------------------------------------------------------|-------------|-------------------------|
| Specific surface area, min, (m²/kg)                     | 20000       | 15000                   |
| Strength active Index with Portland cement at 7 days, min. percentage of control | 122         | ≥105                    |
| Percent retained on 45μm (No.325), max, %               | 9           | ≥10                     |

Table 2. Chemical analysis of condensed silica fume*

| Oxides Composition | Oxide Content (%) | ASTM C1240-5 Limitations |
|--------------------|-------------------|--------------------------|
| SiO₂               | 90.51             | ≥ 85                     |
| Al₂O₃              | 0.60              | -                        |
| Fe₂O₃              | 2.32              | -                        |
| Na₂O               | 0.15              | -                        |
| CaO                | 0.58              | -                        |
| MgO                | 0.30              | -                        |
| TiO₂               | 0.01              | -                        |
| K₂O                | 1.26              | -                        |
| P₂O₅               | 0.10              | -                        |
| SO₃                | 0.35              | ≤ 4                      |
| L.O.I              | 3.82              | ≤ 6                      |

* Test were accomplished at by the National Center for Geological Survey and Mines.

Table 3. Technical explanation Sika-Viscocrete-(5930)*

| Main Action         | Results                        |
|---------------------|--------------------------------|
| Form                | Turbid liquid                  |
| Colour              | Light brown                    |
| Relative density    | 1.080 kg / litre               |
| PH value            | 8.0 ± 1.0                      |
| Viscosity           | 128±1.30 cps @ 20 °C           |
| Transport           | Not classified as dangerous    |
| Labeling            | No hazard label required       |

* According to the manufacturer (The Chemical Company BASF)
3.1 Prepared of bacteria used

The concrete is characterized by high alkalinity between (10-13), so the bacteria used in this research should be suitable for alkaline concrete. The isolated bacteria used from agricultural soils are Bacillus Subtilis (BS). The bacteria were prepared first by preparing the Nutrient Broth Urea (NBU) by dissolving the following feed in each liter of Nutrient Both 5g / l Urea 20g / l and calcium chloride g / l 3. The bacteria were grown at a temperature of 37 ° C in the incubator for 24 hours in incubator 150 rpm. After that bacterial growth, phenotypic tests were performed to confirm the bacterial form and the identification keys in Holt et al. 200 Berges manual. The bacteria returned colony / ml unit by casting in the dishes and the different concentrations of solution bacteria are 10³, 10⁶ and 10⁹ cell / ml as shown in Figure 1 were prepared.

Figure 1. Bacteria Bacillus Subtilis under the micrographic.

3.2 Concrete mixes

Four concrete mixes were intended in this research included, control concrete (reference mix) and three concrete mixes including, the different concentration of solution bacteria (10³, 10⁶ and 10⁹) cell / mm.

3.3 Mix proportion

Control Concrete mixture was designed to conformity to British method for concrete mixes design [13] to achieve compressive strength 41 MPa at 28 days, without any admixtures. The mix proportioning were (1: 1.5: 2), (Cement: Sand: Coarse aggregate) by weight, with a cement content of 450 kg/m³, w/c 0.42 and slump test (100 ± 5 mm). Several trials of concrete mixes were accomplished to choose the optimum dosage of superplasticizer (HRWRA). The w/c ratio was adapted to have the similar workability of the control mix with the slump of (100 ±5 mm). The major function of using superplasticizer HRWRA is to decrease the quantity of mixture water while maintaining a similar workability of the control mixture. The details of the designed control concrete mixture including different dosages of (HRWRA) are presented in Table 4. The empirical results in this examination show that the best dosage of superplasticizer HRWRA is 2 liter per 100 kg of cement, which leads to a water decrease of about 44% and the maximum value of compressive strength of 56.4MPa at 28 days.
Table 4. Details of the trial mixes with various dosages of HRWRA

| Mix Proportions | w/c Ratio | HRWRA (L/100kg of Cement) | Slump (mm) | Water Reduction (%) | Compressive Strength MPa |
|-----------------|-----------|----------------------------|------------|---------------------|-------------------------|
|                  |           |                            |            |                     | 7 Days                  | 28 Days                 |
| 1: 1.5: 2 Cement: Sand: Gravel With cement content of 450 kg/ m³ | 0.42 | 0 | 95 | 0 | 34.7 | 45 |
|                  | 0.38 | 1 | 100 | 9.5 | 36.3 | 47.8 |
|                  | 0.32 | 1.5 | 98 | 23.8 | 42.7 | 53 |
|                  | 0.28 | 2 | 100 | 33.3 | 45.5 | 56.3 |
|                  | 0.27 | 2.5 | 105 | 35.7 | 43.1 | 54.3 |

3.4 Concrete mixing producer

The material mixing procedure was carried out by an electrical rotating container mixer of 0.1m³ volume. All materials mixed by mixture for 5 minute and 70 % of blending water was added to the dry materials then mixed for 1 minute. The superplasticizer was mixed with the 30% remaining mixing water, next it is addition to the mixture and mixed for 2 minutes. Finally, the Bacterial solution added to the mix and mixed 1 minute.

3.5 Preparation, casting and, curing of concrete

Steel molds 100 mm were prepared to clean and oiled before placed of fresh concrete to avoids to adhesion of fresh concrete to the inner surfaces of the molds. Fresh concrete is adding in molds of three layers satisfy the requirements of standard specifications and positioned on the vibration table according to ASTM C-192/C192M [14]. The upper layer of concrete was softened by a steel shovel, and the specimens were covered with a plastic cover for 24 hours to avoid water drying. Subsequent that the specimens were demolded and entirely immersed curing water until the time of the test.

4. Experimental Tests

4.1 Water Absorption

Water absorption test was carried out according to ASTM C642 [15] at the age of 28 days.

4.2 Ultrasonic Pulse Velocity Test

Ultrasonic pulse velocity apparatus test (UPV) was accomplished according to ASTM C597 [16]. The rate result for three 100 mm cube samples is recorded.

4.3 Compressive Strength

The compressive strength test was done on concrete cubes samples of 100 mm according to BS 1881: part 116 [17].

4.4 Scanning Electronic Micrographic (SEM)

The concrete specimen was served for this examination by taking apart from the fracture surface of the concrete. Apart of concrete specimens were dried in a furnace at 60°C for 7days, to remove any moisture in the specimens, after that, these specimens were covered with a light layer of conductive material to prevent the formalization of electric charge when the electron ray scans the specimen.
5. Results and discussion

5.1 Water absorption

The effect of adding different concentrations of bacteria to concrete specimens on water absorption is illustrated in Table 5 and Figure 2. The results showed that, water absorption of concrete decreased with increased concentration of bacterial for all ages of concrete specimens of (15-38) %. The highest reduction in water absorption for concrete specimens was the concentration of $10^6$ cells / mm with a decrease of water absorption (28%) compared to the control specimen. The reducing water absorption was because of the effectiveness of bacteria in depositing layers of calcium carbonate into the cavities, pores and micro-cracks of concrete specimens that seal pores and micro cracks lead improved permeability. The examination of the concrete samples after loading 10% of the compressive strength, the results showed a clear reduction of water absorption relative to control specimen of (23-41%) due to the presence of bacteria that contributing to CaCO$_3$ production, which has reduced the percentage of porous [5].

Table 5. Influence the concentration of bacteria on water absorption

| Symbol Specimens | Water Absorption @ 28 days | Water absorption % after loading 30% of compressive strength |
|------------------|---------------------------|----------------------------------------------------------|
| MR               | 13                        | 22                                                       |
| MB3              | 11                        | 17                                                       |
| MB6              | 8                         | 13                                                       |
| MB9              | 10                        | 15                                                       |

![Figure 2](image.png)

Figure 2. Effect of the different of concentration of bacteria on water absorption

5.2 Compressive strength

Table 6 and Figure 3 show the influence of the concentration of bacteria on the compressive strength of concrete for all ages. Concrete samples containing different concentrations of bacteria increases of
compressive strength compared of to the control specimen are (6- 20), (6-17), (8-22) % and (7-20%) for ages 7, 28, 60 and 90 days respectively. The results showed that the highest improvement was for the concentration of bacteria $10^6$ cells / mm relative of the control specimen. Also, the results showed that the concentration of bacteria increased to $10^9$ cells / mm, which reduced the compressive strength relative to $10^6$ cells / mm. The results showed a remarkable improvement of the concrete specimens after loading 10% of compressive strength of ages 60 and 90 are (25-34%) and (34-39%) to relative the control specimens loaded with 10% of compressive strength. The improvement in compressive strength by biochemistry is due to the effectiveness of microorganisms in the deposition of calcium carbonate in the micro-cracks and voids that act to healing of cracks subjected to loading on the concrete specimens.

Table 6. The effect of concentration of bacteria on compressive strength

| Symbol specimens | Compressive Strength MPa | Compressive strength after loading 10% of compressive strength at 28 MPa |
|------------------|--------------------------|-------------------------------------------------------------------------|
|                  | 7 days  | 28 days  | 60 days  | 90 days | 60 days | 90 days |
| MR               | 34.7    | 45.5     | 48       | 50.5    | 33      | 34.5    |
| MB3              | 38.2    | 47.7     | 51.8     | 53.9    | 41.3    | 46.2    |
| MB6              | 43.3    | 52.5     | 58.3     | 60.7    | 44.3    | 48.0    |
| MB9              | 41.5    | 50.0     | 54.2     | 57.4    | 43.5    | 47.6    |

Figure 3. Influence the concentration of bacteria on compressive strength

5.3 Ultrasonic Pulse Velocity (UPV)

The (UPV) test is used to estimation the uniformity and quality of bacterial concrete, showed the existence of voids and cracks, and develop the depth of the cracks. The completion of UPV of concrete samples containing concentration of bacteria are shown in Table 7 and Figure 4. Concrete specimens containing the concentration of bacteria $10^6$ has less time of transmission than other concentrations of bacteria. And also,
for concrete specimens loaded with 10% of compressive resistance, it a clear improvement in the examination. This is due to the deposition of layers of calcium carbonate, filling the voids and closing the fine cracks inside the concrete.

**Table 7.** The results of UVP for concrete specimens

| Symbol specimen | UVP (km/sec) | UVP (km/sec) after loading 10% of compressive strength at 28 MPa |
|-----------------|-------------|---------------------------------------------------------------|
|                 | 7 days      | 28 days | 60 days | 90 days | 60 days | 90 days |
| MR              | 4.12        | 4.22    | 4.27    | 4.33    | 3.5     | 3.12    |
| MB3             | 4.14        | 4.32    | 4.36    | 4.39    | 3.60    | 3.71    |
| MB6             | 4.23        | 4.38    | 4.40    | 4.51    | 3.75    | 3.85    |
| MB9             | 4.19        | 4.35    | 4.38    | 4.47    | 3.60    | 3.78    |

**Figure 4.** Ultrasonic pulse velocity of concrete specimens

5. 4 Scanning Electron Micrographic (SEM)
Scanning electronic micrograph of control specimen and concrete specimen containing concentration bacteria solution $10^6$ cell/mm after loading 10% of compressive strength at age 28 days of curing prepared in this research was achieved to study the microstructure of that concrete specimens. Figure 5 (a-b-c) displays the image of control concrete without bacteria, where, pores and micro-cracks can be easily seen in the image. Figure 6 (a- b-c)’ demonstrates the SEM analysis of specimen concrete with $10^6$ cell / mm of concentration of bacteria has appeared different calcite crystals formed in concrete. High calcium amounts in it prove that calcite was present in the form of calcium carbonate due to bacteria. Figure 6.-b shows the presence of crystalline calcium carbonate correlating with bacteria. The deposition of calcite
used achieving as barrier to deleterious materials and subsequently improves properties concrete and permeability.

![SEM Images](image1.png)

**Figure 5.** Scanning electron microscopy (SEM) images of fracture surface control concrete without bacteria

![SEM Images](image2.png)

**Figure 6.** SEM images of fracture surface of concrete specimen containing concentration $10^6$ cell/mm of bacteria.

### 6. Conclusions

The main conclusions that can be extracted from this research are:

1. The results showed a decrease in water absorption of (15-38)%, as well as decrease in the concrete specimens of loading 10% of compressive strength of (23-41%) relative to control concrete. The highest reduction was for concrete specimens containing a concentration of $10^6$ cell/mm.

2. Increase in compressive resistance of concrete specimens of (6-20)%, (6-17)%, (8-22)% and (7-20) % for ages 7, 28, 60 and 90 days respectively. Concrete specimen loading 10% of compressive strength
increases are (25-34%) and (34-39%) for 60 and 90 days, relative to compressive strength of control specimens that do not containing bacteria.

3 - It was observed that UPV test of concrete specimens increased because of the time of the transmission of the least wave with the presence of calcium carbonate, which fill the voids and cracks- micro.

4- Scanning Electron Micrographic gave increased in density, deposition of calcite carbonates in the voids and closure of the crack by precipitation of calcium carbonate layers was observed.

Acknowledgments

The authors would like to thank Mustansiriyah University to support this work.

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