# Influential Effect of Self-Healing Treatment on Water Absorption and Electrical Resistance of Normal and Light Weight Aggregate Concretes

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***Abstract*—**Interest in using bacteria in cement materials due to its positive influences has been increased. Cement materials such as mortar and concrete basically suffer from higher porosity and water absorption compared to other building materials such as steel materials. Because of the negative side-effects of certain chemical techniques, biological methods have been proposed as a desired and environmentally friendly strategy for reducing concrete porosity and diminishing water absorption. This paper presents the results of an experimental investigation carried out to evaluate the influence of *Sporosarcina pasteurii* bacteria on the behaviour of two types of concretes (light weight aggregate concrete and normal weight concrete). The resistance of specimens to water penetration by testing water absorption and evaluating the electrical resistance of those concretes was examined and compared. As a conclusion, 20% increase in electrical resistance and 10% reduction in water absorption of lightweight aggregate concrete (LWAC) and for normal concrete the results show 7% decrease in water absorption and almost 10% increase in electrical resistance.

***Keywords*—**Bacteria, biological method, normal weight concrete, lightweight aggregate concrete, water absorption, electrical resistance.

## I. Introduction

STRUCTURAL concrete is a widespread and important material in high tech constructions [1]. Water absorption of cement materials depends mainly on its pore volume, pore structure (whether connected or disconnected), and its distribution within the concrete matrix. Because the aggregate content accounts for 70-75% of the concrete, any improvement in aggregate properties is expected to have an improve effect on concrete properties. Compared to normal weight concrete, however, the aggregates in LWAC are characterized by a higher water absorption, which needs to be reduced. Carbonate precipitate calcium induced by bacteria has been regarded as an environment-friendly material with a promising potential for a wide range of engineering applications. The calcium carbonate precipitated by bacteria filled the concrete's pores, which nowadays forms a potential field of research in concrete technology.

The bacteria induced calcium carbonate precipitation process is an effective and eco-friendly technology that can be applied to solve various environmental problems [2]-[5].

Concrete properties can be measured using a vast variety of methods. One such method is measuring the electrical current passing through concrete specimens as an indicator of the permeability and the ability of concrete to prevent salt intrusion, aggressive materials and gases. Increasing electrical resistance of concrete in this non-destructive, simple, and quick test represents growing durability [6], [7].

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At first researchers thought that microbial induced carbonate precipitation may not be utterly environmental friendly, because ammonium and nitrate are formed during the ureolysis-driven process, which can be toxic and hazardous to human health and soil microorganisms at high concentrations [8]. Ganendra et al. [9] recently found that it was advantageous over ureolysis-driven processes since the calcium formation did not release the ammonia to the air or produce nitric acid when applied to building materials, resulting in decreased risk of pollution and bio-deterioration of the materials [5]. Therefore, using bacteria in concrete and cement base material not only does not damage the environment but also is an eco-friendly strategy compared to chemical solution. The first studies on the properties of calcite deposits were conducted in 1995. Gollapudi et al. used this technique to reduce the porosity of soil with a high permeability by injecting bacteria into soil. For this purpose, they mixed a calcium chloride solution containing urea and carbonic acid directly with the soil and compressed the mixture in a sand column. They found that the pores and cracks in the column were close [10]. Remarkable studies have also been carried out to develop methods that exploit the potential of mineral-producing bacteria for improving concrete properties. Earlier promising results obtained from using different bacteria motivated further investigations that used bacteria in the concrete mix or on the concrete surface [11]-[13]. In 2017, Hosseinibalam et al. [14] conducted extensive research on use of carbonate precipitating bacteria on aggregates using two types of bacteria. This study demonstrated that using bacteria *S. pasteurii* in lightweight aggregate (LWA) named Leca leads a reduction in water absorption about 20% after 6 days of immersion in bacterial solution. The reduced water absorption in LWA may due to the sediments of bacteria which filled the pores. The results show that the aggregates kept the deposits over about 20 days and indicate same results after this time.

Based on the results reported in the above-mentioned studies, and due to the reduced permeability of biologically treated concrete, reduced concrete porosity [15]-[20], the present experimental study was designed to investigate the influence of using calcium-carbonate-producing bacteria on two types of concrete. The properties of concretes are finally evaluated and compared using such indicators as water absorption, and electrical resistance test.

## II. Experimental Program

### A. Bacteria Species Selection and Cultivation

Bacteria *Sporosarcina pasteurii* (*S. pasteurii*) was purchased from Persian Type Culture Collection (PTCC) in Tehran, Iran. This bacterial agent by code number of PTCC 1645 (DSM 33, ATCC 11859, CCM 2056, NCIB 8841, NCTC 4822) was used in the current study as the calcium carbonate precipitating agent. Liquid culture of *S. pasteurii* was grown in media consisting of 8 g/L nutrient broth (peptone: 5 g/L and meat extract: 3 g/L) and pH was adjusted to 7 after the addition of 2% (20 g/L) urea; the nutrient and urea were ordered from Merck company in German. Based on the PTCC recommendation, each medium was supplemented with 10 mg/L $MnSO_4 \times H_2O$ in order to enhance sporulation. In order to be sure about mixing the material with water, the shaker was used to blend them completely. All liquid media were then sterilized by autoclaving by 20 min at 121 ˚C, then all cultured were incubated at 30 ˚C for 48 h and shaken at 300 rpm. Afterwards, the bacterial cells were harvested by centrifuging at 6000 rpm for 20 min. Fig. 1 shows the incubator and autoclaving setup and the centrifuging setup used in this study. The 48 h cells were finally washed twice in the saline solution NaCl, 8.50 g/L.

### B. Mixture Properties and Specimen Preparations

Two types of concrete specimens were made by using cement (CEM I-52.5 N), sand, coarse and fine aggregate and water. Concrete mixes were designed as per ACI 211 [21], [22] to obtain a 28-day compressive strength of 27 MPa. A detailed specification of the concrete mixes is provided in Table I. For light weight aggregate mixes, fine aggregates were submerged in ordinary water for 24 hours and then their surface dried. Specimens were cast immediately after preparation of the mixtures. All the specimens were demolded after the age of 24 h, cured in room temperature of 25±2 ˚C (at 80±5% humidity) until testing time.

### C. Specimen Details and Test Method

As it was mentioned previously, the intent of the current study is to enhance concrete characteristics. To do so, the electrical resistance and water absorption of both concrete specimens were measured at the same age. Concrete specimens were cast in 2 different groups identical in their weights and constituents; they were different, however, in the presence or absence of bacteria in the use of bacteria. Afterward, the specimens were named according their mixture and curing condition in 2 main groups. Table II presents the specifications of the specimens. A three-letter designation was used to label the test specimens (e.g., A-B-C). In this system, A refers to the specimen group name with A denoting the type of concrete. The letter "N" denotes normal weight concrete, and "L" refers to light weight aggregate concrete. B denotes the use of bacteria in the concrete mix water; this is denoted by the letter "Y", and otherwise the letter "N". C stands for the curing environment which included either only water (W) or water containing urea and $CaCl_2$ (this is denoted by the letter 'U'). It must be noted that the experiments were performed in triplicates and the results were reported as average values of three replicates. 18 standard concrete cubes (70 mm in size) were prepared for water absorption test. Furthermore, 18 cylinder specimens, 200 mm in height and 100 mm in diameter, were prepared to measure electrical resistance. The tests were performed at the age of 28 days for water absorption test and 28, 91 and 150 days for electrical resistance test. Improvements achieved in these tests were evaluated against control measurements. The water absorption test was designed as per the standard specified in ASTM C642-13 [23].

TABLE I
MIXING PROPERTIES OF CONCRETE

| | Ingredient | Mass (kg/m$^3$) |
|---|---|---|
| Light weight aggregate concrete | Leca (coarse aggregate) | 456 |
| | Leca (fine aggregate) | 152 |
| | Sand | 527 |
| | Cement | 405 |
| | Water | 160 |
| | Superplasticizer | 0.05 |
| Normal weight concrete | Gravel (coarse aggregate) | 679 |
| | Sand | 1031 |
| | Cement | 368 |
| | Water | 182 |

The electrical resistance, which is a non-destructive test quick to perform, was completed according to codes ASTM C1760-12 [24]. Prior to the test, the surface of the saturated specimens was dried. They should be placed between two cells and their junction with the cells was sealed with glue. Cylindrical specimens are used and a current of 60 V is applied for 1 minute. The temperature of each specimen was set between 20 and 25 °C at the start of the test and both cells were filled with sodium chloride (3% weight) solution. All the connections were made in series to the power supply and the voltmeter. A 60-V power was then applied to both ends of the specimen and the current was recorded after one minute. Electrical conductivity (the converse of electrical resistance) was calculated using:

$$\sigma = K \frac{I_1}{V} \frac{L}{D^2}$$

where, σ is the electrical conductivity of concrete in $\frac{m}{\Omega.m}$, $I_1$ is the current in mA measured after 1 minute, V is the applied voltage in volts and is equal to 60, D is the average diameter of the specimen in mm and equal to 100, L is the average height of the specimen in mm and equal to 200, and K is a constant equal to 1273.2 .

Electric resistance was obtained from:

$$R = \frac{10^{+3}}{\sigma}$$

where, R is the electrical resistance of concrete in Ω.m and σ is the electrical conductivity of concrete in $\frac{m}{\Omega.m}$.

## III. Experimental Results and Discussion

### A. Water Absorption

Fig. 2 depicts the values for the water absorption of specimens submerged in water and in the urea-CaCl2 solution at curing ages of 28 days. As seen in Fig. 2, specimens remediated with bacteria exhibit lower water absorption in all groups than the control specimens. The water absorption of the normal weight aggregate concrete specimen treated with bacterium-containing concrete mix water is about 3.57%, which is lower by about 6.5% than those of the control specimens submerged only in water. As depicted in Fig. 2, the light weight aggregate concrete specimens in the L-Y-U group submerged in the urea-$CaCl_2$ solution exhibit lower water absorption than the control ones submerged only in water; this might be attributed to the positive side effects of sediments filled the pores. Although the specimens in the L-Y-U group submerged in the urea-$CaCl_2$ solution exhibit higher water absorption than those in the N-Y-U group cured in the same environment, the water absorption of each group relative to their control ones has been improved. It may, therefore, be concluded that treating concrete mixes with bacteria may reduce, although not adequately, the influence of bacterial remediation directly depends on the pore structure of the concrete.

TABLE II
SPECIFICATION OF SPECIMENS

| Type of concrete | Bacteria | Curing condition | Specimens label |
|---|---|---|---|
| Normal weight | yes | Urea-$CaCl_2$ | N-Y-U |
| Normal weight | no | Urea-$CaCl_2$ | N-N-U |
| Normal weight | no | water | N-N-W |
| Light weight aggregate | yes | Urea-$CaCl_2$ | L-Y-U |
| Light weight aggregate | no | Urea-$CaCl_2$ | L-N-U |
| Light weight aggregate | no | water | L-N-W |

(a) (b) (c)

Fig. 1 Setup used for culturing the bacteria; (a) Shaker; (b) Autoclave setup; (c) Incubator

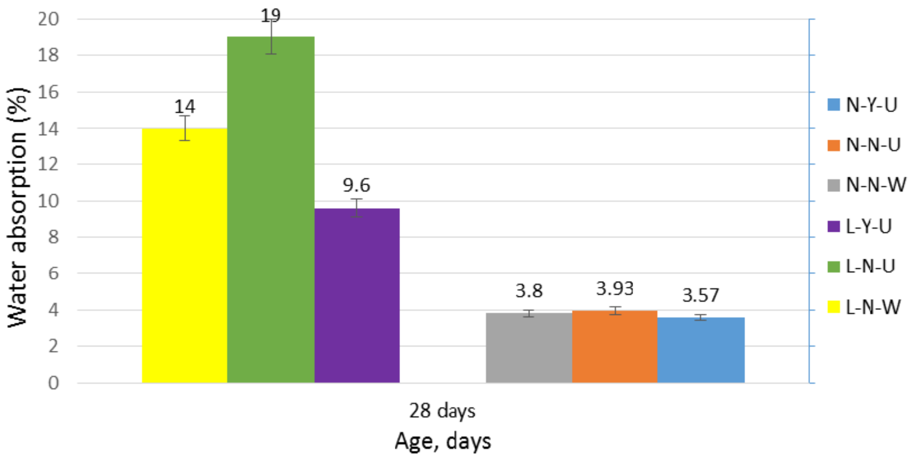


Fig. 2 Water absorption of concrete specimens at 28 days

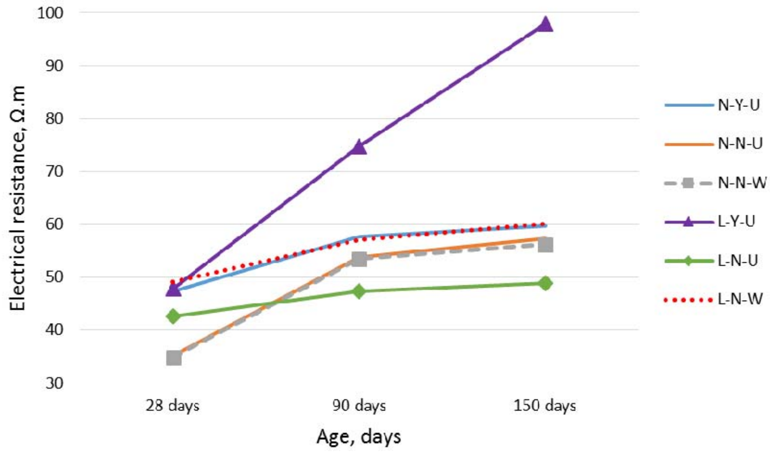


Fig. 3 Electrical resistance of concrete specimens



*B. Electrical Resistance*

Fig. 3 shows the electrical resistance results for LWAC and normal weight aggregate concrete with and without bacteria. The results imply that using of bacteria, for both types of concrete, enhances the electrical resistance. The current passing through the specimen at the age of 91 days in N-Y-U is 57.75 Ω.m that is respectively about 53.73 Ω.m and 53.5 Ω.m for those of N-N-U and N-N-W (control specimens submerged in urea-CaCl2 solution and water). Comparison between the groups L-Y-U and L-N-U (control specimens with no bacteria submerged in urea-CaCl2 solution) and L-N-W (control specimens with no bacteria submerged in water) shows that when the specimens submerged in urea-$CaCl_2$ solution, the current passing through specimens increased about 30%.

Given the higher electrical resistance of the bacterial specimens compared to those of the control group, it may be claimed that the formation of calcite sediments in the concrete pores leads to improvement in concrete pore fluid conductivity and electrical resistivity.

## IV. Conclusions

This paper investigated the effects of bacterial strains of *Sporosarsina pasteurii* on treatment of normal and light weight aggregate concrete. Furthermore, the effect of using bacterial sediments on water absorption and electrical resistance in concrete mixture with bacteria in mix water or without bacteria was studied. Based on the results, the following conclusions are drawn with respect to the bacterial concentrations employed:

- Among all the concrete specimens, those containing *S. pasteurii* exhibited lower water absorption, and higher electrical resistance as compared to specimens without bacteria.
- Water absorption was observed to decrease in specimens containing bacteria relative to those lacking bacteria. In the case of normal and light weight aggregate concrete mixtures, the greatest reduction in water absorption (up to 49%) and increase in electrical resistance up to 50% was observed for the light weight aggregate concrete specimens with *S. pasteurii* cured in urea-calcium chloride solution.
- Overall, it was observed that bacterial sedimentation has a more significant on light weight aggregate concrete than on normal weight concrete. In that case the electrical resistance of light weight aggregate concrete increased by about 30% while water absorption decreased by 40%.

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