

Reservation and Development of Rigid Pavement Quality with the Aid of Bacteria

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Abstract— Initiation of Microcracks in rigid pavement usually starts within few hours of casting due to the shrinkage of concrete and casting at hot environment condition. Cracking proceeds and changes to macrocracks throughout the service life of the pavement due to repetitions of compressive, tensile, and shear stress under wheel loading. Such cracking exhibits a durability problem since the ingress of moisture and harmful chemicals such as sulphates and chlorides into the concrete through the cracks can cause premature matrix degradation and corrosion of embedded steel reinforcement at joints, which may result in the decrement of strength and service life. In this work, implementation of self-healing techniques was adopted with the aid of bacteria and healing agent to precipitate CaCO_3 on the formed micro-cracks. The precipitation of calcite by continuous hydration of cement helps in production of calcium carbonate precipitation with the help of bacteria. A soil bacterium named *Bacillus subtilis* was cultured in the laboratory, the concentration of bacteria cell of *B. subtilis* in normal saline (NaCl , 9 g/l) suspension was 10^6 cell/ml. Concrete specimens of various type (cube of $100 \times 100 \times 100$ mm, cylinder of 100mm diameter and 200mm height, and beam of $100 \times 100 \times 500$ mm) size have been prepared in the laboratory, then separated to three sets. The first set of specimens were subjected to controlled compression and flexure pre-cracking, then subjected to healing and curing in a water bath which contains the prementioned bacteria at 20°C for 7 days. The second set was the control specimens cured in water bath for 7 and 28 days at 20°C . The third set of specimens were subjected to healing and curing in a water bath which contains the prementioned bacteria at 20°C for 7 and 28 days and then tested for compressive, indirect tensile, and flexure properties. It was observed that the healing process provided by the bacteria have improved the overall properties of concrete by (23, 11 and 16) % for compressive, tensile and flexure strength respectively as compared to those of control mixture after 28 days of curing. On the other hand, specimens subjected to controlled pre-cracking exhibit improvement in strength properties after the healing process provided by the bacteria by (28 and 33) % for compressive and flexure strength respectively as compared to those of control mixture after 7 days of curing. It was concluded that spraying of bacterial water for curing the concrete is beneficial and can be considered as sustainable and environment friendly solution for maintenance. Bacteria can reserve, develop and maintain the quality of rigid pavement.

Index Terms— Reservation, Quality, Concrete, Bacteria, Microcrack healing, Rigid pavement

I. INTRODUCTION

Cement Concrete is commonly used material for construction of rigid pavement for airport and major arterials in Iraq. Micro Cracks usually occurs after casting due to shrinkage phenomena or through the service life due to various mechanisms such as temperature gradient of thick pavement, repeated loading, and Freeze-thaw cycles. Maintenance of cracks of macro size is a routine work, but the problem arises when micro cracks exists, (Sarsam, 2016). Cracks tend to expand further and eventually require costly repair. If micro cracks grow and reach the reinforcement, the reinforcement may corrode when it is exposed to water and oxygen and possibly carbon dioxide and chlorides (indirect degradation), (Nivedhitha, et al, 2016). Research has shown that autogenous healing happens due to hydration of non-reacted cement particles present in the concrete matrix when encounters ingress water resulting in closure of micro cracks. The inbuilt bacteria-based self-healing process was found to heal cracks completely up to 0.5 mm width, (Rao et al, 2013). Novel technique has been developed by using a selective microbial metabolic activity promote calcium carbonate (calcite) precipitation, (Karthik and Rao, 2016). At the point when broken segment blended in microscopic organisms interacts with fresh concrete, cracked surfaces are enacted within the sight of water, and after that starts to multiply and precipitate minerals. These minerals, including calcium carbonate close the crack. The microscopic organisms should act as an impetus and change an antecedent compound, for example, calcium carbonate-based mineral accelerates, into an appropriate filler material, (Vipu et al, 2017). Bacterial concrete helps in increase the strength of concrete by the action of calcium precipitation of bacteria and it proves to be cost effective. Bacterial concrete increases compressive strength up to 20%. The cost of bacterial concrete increased 7-15% more than conventional concrete, (Patil et al, 2017). It was stated by (Prabakar et al, 2017) that the use of bacterial concrete is one of the ecofriendly techniques for crack healing. This technique uses the calcium precipitate produced by bacterial metabolic activities to heal cracks. Bacterial concrete shows greater strength and durability than normal concrete. The addition of *Bacillus Subtilis* bacteria showed significant improvement in the compressive, split tensile and flexural strength than the conventional concrete. It was concluded that bacteria can be easily cultured and safely used

in improving the strength characteristics of concrete, (Sarsam et al, 2018). The outcome of a study by (Schlangen et al, 2010) shows that crack healing in bacterial concrete is much more efficient than in concrete of the same composition but without added biochemical healing agent. The reason for this can be explained by the strictly chemical processes in the control and additional biological processes in the bacterial concrete. It was concluded by (Bhagyashri et al, 2017) that the greatest improvement in compressive strength occurs at cell concentrations of 105 cells/ml for all ages. The study showed that a 25% increase in 28-day compressive strength of cement mortar was achieved. Enhancement of compression strength, reduction in permeability, water absorption has been seen in various cementitious and stone materials. The nutrients for the bacteria which can precipitate calcite are calcium sources, phosphorous and nitrogen sources. These bacterial components remain dormant in concrete, when the seepage of water take place into the formed cracks helps in reacting with the nutrient to precipitate calcite i.e., CaCO_3 (Klaas van Breugel, 2012). Bacterial induced calcium carbonate deposition has been proposed as an alternative and environmentally friendly crack repair and self-healing technique for reservation of concrete quality. The precipitation of CaCO_3 helps in sealing the micro cracks. It was concluded by (Krishnapriya et al, 2015) that bacteria are suitable for use in concrete as it had resulted in increased strength and complete healing of cracks in concrete specimens. The inclusion of these bacteria in concrete will result in high strength, crack free and durable concrete structures in the future.

Based on the above introduction, the present investigation will consider implementation of *Bacillus subtilis* bacteria in the curing water of concrete to study its influence on the compressive, tensile, and flexural strength of concrete before and after pre-cracking.

II. MATERIAL CHARACTERISTICS

A. Ordinary Portland Cement

The Iraqi Ordinary Portland cement (type 1) with a commercial name of (Tasluga) was implemented throughout the present work. Table 1 exhibit the chemical composition of cement, while Table 2 presents the physical properties of cement.

TABLE 1
CHEMICAL COMPOSITION OF CEMENT

Oxide	% by weight	Limit of Iraqi specification No.5/ 1984
CaO	61.28	-----
SiO ₂	18.372	-----
Al ₂ O ₃	3.58	-----
Fe ₂ O ₃	5.02	-----
MgO	1.39	< 5.0
SO ₃	2.02	< 2.80
C ₃ A	0.988	-----
Loss on ignition	2.85	≤ 4.0
Insoluble residue	1.07	< 1.5
Lime saturated Factor	1.0148	≥ 0.66 ≤ 1.02

TABLE 2.
PHYSICAL PROPERTIES OF CEMENT

Physical properties	Test result	Limits of Iraqi specification
Specific surface area, Blain's method m ² /kg	394	≥ 230
Soundness, Autoclave's Method, %	0.03	< 0.8
Setting time, Vicat's method		
Initial setting hour: min	2:15	≥ 45 min
Final setting hour: min	3:30	≤ 10 hours
Compressive strength		
3 days N/mm ²	20.7	≥ 15
7 days N/mm ²	26.1	≥ 23

B. Aggregate

Crushed gravel with a nominal size of (19 mm) was obtained from Nibae region and used in this work. The properties of coarse aggregate are shown in Table 3. Fine aggregate of maximum size 4.75mm was obtained from Al-Ukhaider quarry and used, the properties of fine aggregate are shown in Table 3. The combined gradation implemented is illustrated in Table 4.

TABLE 3.
PROPERTIES OF COARSE AND FINE AGGREGATES

Type of aggregate	Bulk Specific Gravity	Density(kg/m ³)	Absorption %	SO ₃ %
Crushed aggregate	2.630	1646	1.167	0.034
Fine aggregate	2.603	1789	9.3	0.126

C. Water

The water used in mixes was drinking water of Baghdad area. This water was also used for curing.

TABLE 4.
COMBINED GRADATION ADOPTED

Sieve size mm	19	12.5	9.5	4.75	1.18	0.3	0.15
Percentage finer by weight	100	85	70	59	46.4	16	3.3

III. METHODOLOGY

The methodology implemented in this investigation consist of three steps, in the first step, Culture and growth of bacteria (*Bacillus subtilis*) in the laboratory was conducted. The second step was preparation of concrete specimens (cubes, cylinder and beams), and pre-cracking was applied for cubes and beam specimens. In the third step, curing of the specimens was conducted in bacterial water then the strength properties of concrete specimens were evaluated after seven and 28 days of curing.

A. Preparation, Isolation and Culture of Bacteria *Bacillus Subtilis*

The isolation and culture of bacteria *bacillus subtilis* starts by collection of soil samples from Agricultural areas in Baghdad city and evacuation in glass bottles. The soil sample was then mixed with distilled water and shaken vigorously to ensure thorough mixing. Serial dilution was made by transfer of 1 ml of soil suspending to 9 ml of distilled water in test tube, this soil

suspension is of 10^{-1} dilution. After mixing this solution in vortex mixer, one ml of 10^{-1} dilution was transfer to 9 ml of distilled water, then the concentration of solution becomes 10^{-2} dilutions. This process was repeated until 10^{-6} dilution is obtained. The concentration of bacteria cell of bacillus subtilis in suspension was 10^6 cell/ml. The preparation, isolation and dilution details of the bacteria were published elsewhere, (Sarsam et al, 2018). Figure 1 exhibit the isolation of the bacteria, while Figure 2 shows the culture and dilution of the bacteria.



Fig. 1. Isolation of the bacteria.



Fig. 2. Culture and dilution of the bacteria

B. Preparation of Control Concrete Mixture

Control concrete mixture was designed as per ACI 211.1-91 method, such mixture is usually used for rigid pavement construction. The mix proportion is (1:1.5:3.75) with 0.45 water cement ratio. Cube, beam and cylinder specimens have been prepared, covered with polythene sheets to retain the mixing water for curing for 24 hours. Specimens were immersed in water with bacterial concentration of 10^6 cell/ml of water. Calcium lactate of 5% by weight of cement were added to the bacterial water. Specimens were tested after seven and 28 days to assess the impact of curing in bacterial water on the physical properties.

C. Pre-cracking of specimens

To simulate the concrete condition during service in the field, and to determine the effectiveness of bacteria in the crack healing process, specimens were subjected to controlled pre-cracking in the laboratory. Many trial specimens have been subjected to various compression and flexural loading, then tested for strength to check that it does not reach the failure condition. Cube specimens were subjected to pre-cracking after 24 hours of curing, a load of 260 kN was applied for one minute then released. Cube specimens were subjected to ultrasonic

wave traverse with the aid of pundit to determine the time required for the sound to traverse the specimen before and after the pre-cracking process. For beam specimens, the pre-cracking was conducted using a flexure load of 5kN, while the ultrasonic wave traverse along the length of the beam. The time required for the sound to traverse the specimen before and after the pre-cracking process was recorded.

IV. RESULTS AND DISCUSSION

A. Strength properties after pre-cracking

Six cubes are tested after a curing period of 7days, 28days, for every age period 3 cubes are casted. Control cubes were also prepared and tested for comparison. The size of cube is (100x100x100) mm. Beam specimens of (100 x 100) mm of section and 500 mm length have been prepared and tested in duplicate. Figure 3 exhibit the flexural and compressive strength of the pre-cracked specimens after seven days of curing in bacterial water, it can be noticed that the compressive strength increases by 28.5 %, while the flexural strength increases by 33 % after curing in bacterial water for seven days as compared to the case for control specimens.

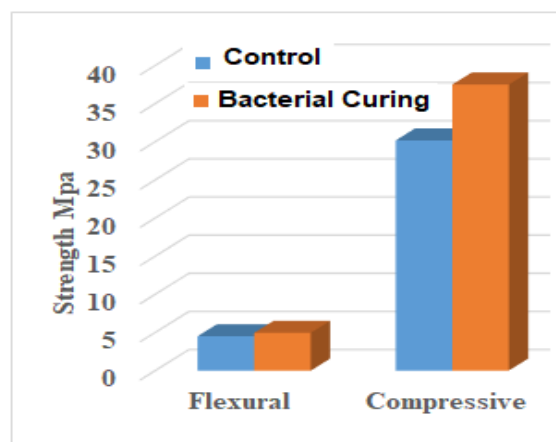


Fig. 3. Strength properties after pre-cracking and curing for seven days

B. Specimens for Compressive Strength test

Figure 4 shows the compressive strength determination of cube specimen. The compressive strength test results for both conventional and bacterial cured concrete are shown in Figure 5. It can be observed that the bacterial cured concrete exhibit high compressive strength when compared to that of control concrete. The variation was (107 and 23) % after 7 and 28 days of curing respectively. On the other hand, the increment in compressive strength after 28 days of curing was (95.5 and 18.4) % for control and bacterial concrete respectively.



Figure 4. Compressive strength test

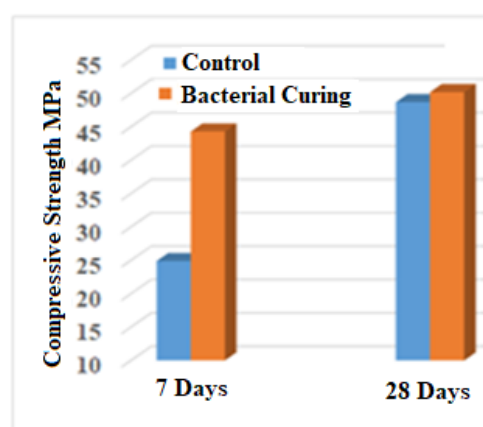


Fig. 5. Compressive Strength of pre-cracked specimens

C. Specimens for Splitting Tensile test

Figure 6 shows the Indirect (splitting) tensile strength determination of cylinder specimen. The test is carried out after casting and curing cylindrical specimens of dimension 100mm diameter and 200mm height, specimens were tested for indirect tensile strength. The load was applied until failure of the specimen along the vertical diameter. The tensile strength was calculated based on the failure load. It can be noticed from Figure 7 that the bacterial cured concrete exhibit high tensile strength when compared to that of control concrete. The variation was (5 and 10.7) % after 7 and 28 days of curing respectively. On the other hand, the increment in tensile strength after 28 days of curing was (8.3 and 14.2) % for control and bacterial cured concrete respectively.



Fig. 6. Indirect Tensile strength test

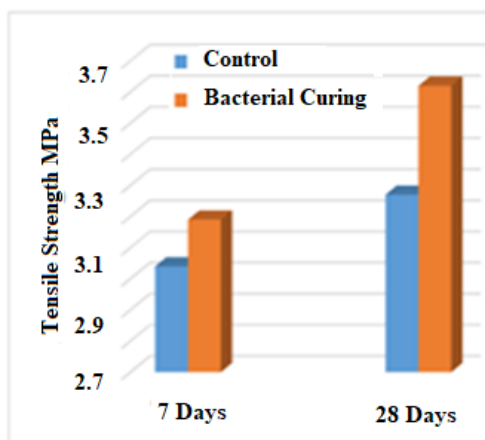


Fig.7 . Tensile Strength of pre-cracked specimens



Fig. 8. Flexural strength test

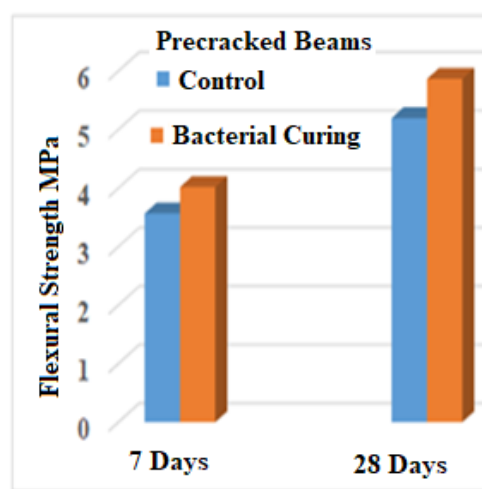


Fig. 9.. Flexural Strength of specimens

D. Specimens for Flexural strength test (four-point loading)

The test is carried out after casting and curing of beam specimens in bacterial water to find the flexural strength of the concrete. Control specimens were also prepared and tested for comparison. The beam specimens were placed in the machine in such manner that the load is applied to the uppermost surface as cast in the mold. Two points loading was adopted on an effective span of 450 mm while the beam rest on two supports. The load is applied until the failure. Figure 7 exhibit the flexural strength setup while Figure 8 shows the flexural strength of control and bacterial cured concrete. It can be noticed that the bacterial cured concrete exhibit high flexural strength when compared to that of control concrete. The variation was (22.5 and 16) % after 7 and 28 days of curing respectively. On the other hand, the increment in flexural strength after 28 days of curing was (38 and 48.7) % for control and bacterial cured concrete respectively. Such behavior may be attributed to the micro crack healing by precipitation of CaCO_3 in the microcracks.

CONCLUSIONS

Based on the testing program, the following conclusions can be drawn

- 1- Implementation of bacteria (*Bacillus subtilis*) in the curing water exhibit a positive influence on reservation and development of the strength properties of concrete.
- 2- Bacterial cured concrete exhibit high compressive strength of (107 and 23) % after 7 and 28 days of curing respectively when compared to that of control concrete. The increment in compressive strength after 28 days of curing was (95.5 and 18.4) % for control and bacterial concrete respectively.
- 3- Bacterial cured concrete exhibit high tensile strength of (5 and 10.7) % after 7 and 28 days of curing respectively when compared to that of control concrete. The increment in tensile strength after 28 days of curing was (8.3 and 14.2) % for control and bacterial concrete respectively.
- 4- Bacterial cured concrete exhibit high flexural strength of (22.5 and 16) % after 7 and 28 days of curing respectively when compared to that of control concrete. The increment

in flexural strength after 28 days of curing was (38 and 48.7) % for control and bacterial concrete respectively.

- 5- Specimens subjected to controlled pre-cracking exhibit improvement in strength properties after the healing process provided by the bacteria by (28 and 33) % for compressive and flexure strength respectively as compared to those of control mixture after 7 days of curing in bacterial water.

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