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Implementation of Bacteria for Microcrack Closer of Concrete

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ABSTRACT

Hot-weather casting of concrete pavement is usually accompanied with initiation of microcracking. Such cracking can exhibit a durability problem since it allows the ingress of water and harmful chemicals such as sulphates and chlorides into the concrete which may cause premature corrosion of the steel reinforcement, and concrete matrix degradation. Implementation of bacteria as a healing agent to precipitate $CaCo_3$ on the formed micro-cracks can support the durability. The continuous precipitation of calcite by hydration of cement helps in production of calcium carbonate precipitation with the help of bacteria. In this work, Bacillus subtilis bacteria of soil origin was cultured in the laboratory, the concentration of bacteria cell in normal saline (NaCl, 9 g/l) suspension was 10^6 cell/ml. Concrete beam specimens of (100 x 100 x 500 mm) size have been prepared in the laboratory, then separated to three sets. The first set was the control specimens cured in water bath for 7 and 28 days at 20°C. the second set of specimens was subjected to controlled flexure pre-cracking, then subjected to healing and curing in a water bath which contains the prementioned bacteria at 20°C for 7 days for healing and curing. The third set was 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 flexure properties. It was noted that the healing process by bacteria have improved the flexural properties of concrete by (16) % as compared to those of control mixture after 28 days of curing. On the other hand, specimens practiced the controlled pre-cracking exhibit (33) % improvement in flexural strength properties after the healing process provided by the bacteria. as compared to those of control mixture after 7 days of curing. It was concluded that implementation of bacteria in the curing water of concrete can furnish the required healing concept of microcracking in concrete. Such technique can be considered as an eco-friendly and sustainable solution for maintenance.

Keywords: *Bacteria, Maintenance, Concrete, Pavement, healing, pavement*

INTRODUCTION

Concrete is usually used for construction of rigid pavement. When casting the concrete in hot weather condition of above 40°C, microcracking occurs due to quick evaporation of water which is required for the chemical curing process of cement. Maintenance of such microcracks is immediately required. Jonkers et al., [1] stated that durability of the pavement is the primary concern for concrete engineers. Concrete paving has a high tendency to cracking, which allows aggressive species to penetrate the matrix. External loads, temperature gradients, and restrained deformation are the main factors contributing to the crack. Nivedhitha, et al, [2] stated that cracks tend to expand further and reach the reinforcement, which may corrode when it is exposed to water and oxygen and possibly carbon dioxide and chlorides.

Deterioration of the concrete matrix can occur and eventually require costly repair as reported by Sarsam, [3]. Research conducted by Rao et al, [4] has shown that autogenous healing happens due to inbuilt bacteria and hydration of non-reacted cement particles present in the concrete matrix when encounters ingress water resulting in closure of micro cracks. The self-healing process was found to heal cracks completely up to 0.5 mm width.

Technique has been developed by Karthik and Rao, [5] using a selective microbial metabolic activity promote $CaCo_3$ (calcite) precipitation, the calcium carbonate closes the crack. Xu et al., [6] stated that ureolysis-based bacterial spores were applied in mortar to serve as self-healing agents.

The healing effect was evaluated by compressive tests before and after healing. Efficiency of healing was also studied by crack imaging analysis and water uptake measurements. Vipu et al., [7] reported that the microscopic organisms can act as an impetus and change calcium carbonate-based mineral

accelerates, into an appropriate filler material. Abdullah et al., [8] reported that any type of bacteria with ability to metabolically convert calcium source into calcium carbonate, can be implemented in producing autogenous healing concrete. However, it is important to provide protection to bacteria in concrete to sustain the self-healing ability throughout the life span of concrete.

It was concluded that bacterial concrete has lower strength as compared to conventional concrete with the same mixture ingredient. Bacterial concrete able to fully repair visible crack autogenously compared to conventional concrete. Addition of bacterial into concrete helps in increase the strength by the action of calcium precipitation of bacteria and it proves to be cost effective as reported by Sarsam et al., [9].

Bacterial concrete exhibit flexural strength of (23.3 and 20.1) % higher after 7 and 28 days of curing respectively when compared to that of control concrete. However, the cost of bacterial concrete increased by (7-15) % more than conventional concrete as reported by Patil et al, [10]. The amount of bacteria spore incorporated into the concrete may increase the rate of crack-sealing, but nutrients are needed to produce $CaCO_3$ after spore being activated by water. The amount of nutrients will limit the amount of $CaCO_3$ as in the following reaction [11]:

$$CaC_6H_{10}O_6 + 6O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O$$

It was stated by Prabakar et al, [12] that 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.

As stated by Sarsam and Suliman, [13], it can be noted that bacteria can be easily cultured and safely used in improving the strength characteristics of concrete. Schlangen et al, [14] investigated healing in bacterial concrete, it was stated 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 stated by Bhagyashri et al, [15] that the greatest improvement in compressive strength occurs at cell concentrations of 10^5 cells/ml for all ages. The study showed that a 25% increase in 28-day compressive strength of cement mortar was achieved.

Klaas van Breugel, [16] reported that 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.

Bacterial induced calcium carbonate deposition has been proposed as an alternative and environmentally friendly crack repair and self-healing technique. The precipitation of Ca Co_3 helps in sealing the micro cracks. Puranik et al., [17] stated that significant increase in compressive strength with the addition of bacteria could be observed. 30 ml of Bacillus Sphaericus in concrete mix M20 shows the maximum improvement in compressive strength as compared with the conventional concrete's strength. Krishnapriyaa et al, [18] concluded that bacteria is 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.

The present investigation will consider implementation of Bacillus subtilis bacteria in the curing water of concrete to study its influence on the flexural strength of concrete before and after pre-cracking.

Materials and Methods

Portland Cement

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

Coarse and Fine Aggregates

Crushed gravel with a nominal size of (19 mm) obtained from Nibaee region was implemented in this work. The properties of coarse aggregates are exhibited in Table 3.

Fine aggregates of maximum size 4.75mm obtained from Al-Ukhaider quarry was used, the properties of fine aggregates are shown in Table 3. The combined gradation implemented is illustrated in Table 4.

Table1. *Chemical composition of cement*

Oxide	% by weight	Limit of Iraqi specification No.5/ 1984
CaO	61.28	--------
SiO2	18.372	--------
Al2O3	3.58	--------
Fe2O3	5.02	--------
MgO	1.39	< 5.0
SO3	2.02	< 2.80
C_3A	0.988	--------
Loss on ignition	2.85	≤ 4.0
Insoluble residue	1.07	< 1.5
Lime saturated Factor	1.0148	≥ 0.66 ≤ 1.02

Table2. *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 Final setting hour: min	 2:15 3:30	 ≥ 45 min ≤ 10 hours
Compressive strength 3 days N/mm^2 7 days N/mm^2	 20.7 26.1	 ≥ 15 ≥ 23

Table3. *Properties of course and fine aggregates*

Type of aggregate	Bulk Specific Gravity	Density (kg/m^3)	Absorption %	SO_3 %
Crushed aggregates	2.63	1646	1.167	0.03
Fine aggregates	2.5	1789	9.3	0.12

Table4. *Combined gradation adopted*

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

Water

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

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 beam specimens, and pre-cracking was applied for 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.

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. After all these steps, petri-dishes plates with nutrient agar media according to the bacteria requirement have been prepared.

The solution of concentration 10^{-4} to 10^{-6} was spread by cotton swab on the petri-dishes plate with nutrient agar media in it and incubated in 37 °C to 24 hours in the incubator. After 24 hours, the plates are taken out from incubator, the type of colony formation in the Petri dish plate was checked.

Some more petri-dishes plates with the same media and soil sample with different concentration have also been prepared. After this, the different type of colonies on different

plates were observed and the growth after 24 hours incubation was checked.

The morphology of different colonies was checked by gram staining method. The urease test method and vitek 2E compact system have been implemented for identification of bacillus subtilis. Afterword, Preparation of the concentration 10 ^{6} of bacterial cell (bacillus subtilis) starts by Transfer of loop full of single colonies of bacillus subtilis that form urease enzyme from nutrient agar to brain heart broth media and incubation at 37 °C on shaker at 150 rpm for 24 hours. The harvest of bacterial cell was done by centrifuge the 24 hour's old grown culture (5000 rpm, 5 minutes). The sediments (bacterial cell) were form after centrifuge and were re-suspended in normal saline (NaCl, 9 g/l). The concentration of bacteria cell of bacillus subtilits in suspension was 10^{6} cell/ml. Figure 1 exhibit the isolation of the bacteria, while Figure 2 shows the culture and dilution of the bacteria.

Figure1. *Isolation of the bacteria*

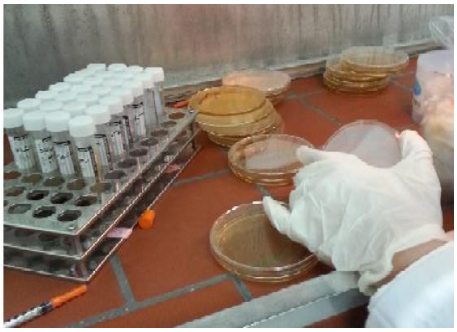

Figure2. *Culture and dilution of the bacteria*

Preparation of 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. Beam specimens have been prepared, covered with polythene sheets to retain the mixing water for curing for 24 hours. Specimens were immersed in water tank with bacterial concentration of 10^{6} cell/ml of water. Calcium lactate of 5% by weight of cement was 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.

Pre-Cracking of Specimens

To simulate the concrete condition during curing and 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 flexural loading, then tested for strength to check that it does not reach the failure condition. The pre-cracking was conducted using a flexure load of 5 kN, while the ultrasonic wave traverse continuously along the length of the beam to check not to reach failure. The time required for the sound to traverse the specimen before and after the pre-cracking process was recorded.

Results and Discussions

Strength Properties after Pre-Cracking

Beam specimens of (100 x 100) mm of section and 500 mm length have been prepared and tested in duplicate. Table 5 exhibit the flexural strength of the pre-cracked specimens after seven and 28 days of curing in bacterial water, it can be noticed that the flexural strength increases by (0.75 and 1.8) % after curing in bacterial water for seven and 28 days respectively.

Table5. *Flexural strength of beam specimens*

Age (days)	Flexural strength (MPa)	
	Control	Bacterial water curing
7	2.65	2.67
28	4.4	4.48

Ultrasonic Wave Traverse Time

Beam specimens have been subjected to ultrasonic wave traverse time determination before and after pre-cracking process and after bacterial curing to assess the influence of bacterial curing in the crack healing process. Control specimens were also tested for comparison. Figure 4 exhibit the impact of bacterial curing on the ultrasonic wave traverse time for beam specimens. It can be observed that longer time was required to traverse the pre-cracked specimen as compared to the control and healed specimens immersed in bacterial water. This may be attributed to the lower voids after bacterial curing due to precipitation of $CaCo_3$. After pre-cracking, the time taken by ultrasonic wave to traverse the beam was higher by (20 to 7) % for control and bacterial cured specimens respectively as compared to the case before pre-cracking.

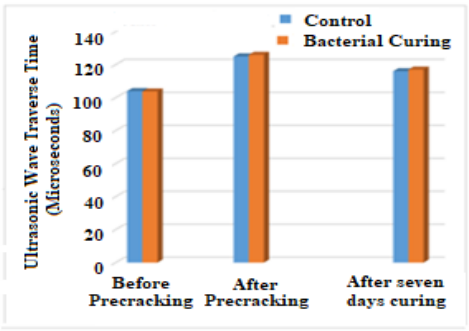

Figure3. *Ultrasonic wave traverse time for pre-cracked specimens*

After seven days of curing, the variation of the ultrasonic wave traverse time was not significant among control and bacterial cured cubes. This could be attributed to the possible 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 as mentioned by Krishnapriyaa et al., [18]. On the other hand, the curing period of seven days was effective in healing the microcracks for both control and bacterial cured specimens and the ultrasonic wave traverse time was almost equivalent to that before pre-cracking condition.

Determination of Flexural Strength (Four-Point Loading)

The test is carried out after casting and curing 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 4 exhibit the flexural strength test setup while Figure 5 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.

Figure4. *Flexural strength test*

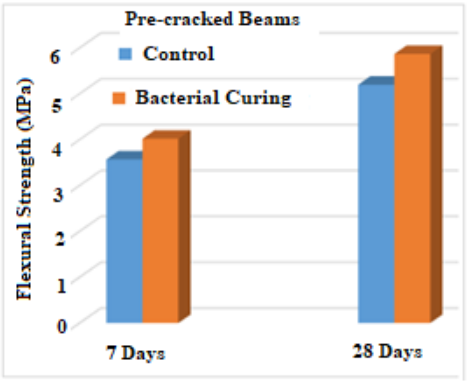

Figure5. *Flexural Strength of specimens*

CONCLUSIONS

Based on the limitations of materials implemented, and the testing program, the following conclusions can be drawn

1. Implementation of bacteria (Bacillus subtilis) in the curing water exhibit a positive influence on the strength properties of concrete.
2. 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.
3. Specimens subjected to controlled pre-cracking exhibit improvement in strength properties after the healing process provided by the bacteria by (33) % for flexure strength as compared to those of control mixture after 7 days of curing in bacterial water.
4. Bacterial water is recommended for curing and healing of microcracks in concrete pavement, it can be applied within 24 hours after casting.

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