Application of Biotechnology-Based Method for Ehancing Concrete Properties

A. Vahabi, K. Akbari Noghabi, and A. A. Ramezanianpour

***Abstract*—Concrete is increasing worldwide as a significant partial of structure because it is robust and cheap. However, porosity is an ordinary phenomenon in concrete that has detrimental effects on concrete properties such as reduction of compressive strength. In this research, a novel biotechnology-based method using a specific strain was applied to improve compressive strength of specimens. For this purpose, the specific strain with the ability of mineral precipitation was isolated from alkaline soil by using an enrichment culture technique. Therefore, identification of calcium carbonate-based mineral precipitations was examined by Fourier-Transform Infrared (FT-IR) spectrometry. *Bacillus* sp. LS1 as an indigenous strain was applied in mortar specimens to determine its effect on compressive strength. Finally, bacterial mortars revealed a significant increasing compressive strength in comparison to control specimens. In conclusion, result of this study is appeared to be promising and overall viewpoint can be demonstrated as an alternative for improving concrete properties.**

***Index Terms*—Bacterial mortar, calcium carbonate, compressive strength, FT-IR.**

I. Introduction

Compared with most building materials, production of concrete require less primary energy. In addition, large amounts of industrial wastes can be reused as aggregate in construction materials, cement are used. So, in the future with regard to energy efficiency in the use of concrete as a building material can be further considered, for better introducing cement as a universal material with worldwide application it is undeniable that in many cases cement is the only material which can be used in industrial process, Even in cases where other materials are used as the main building, the concrete with a certain proportion, will be used in other areas. Concrete can withstand the load, enclosed spaces, surface coating, and filling volume used in public buildings [1]. On the other hand, it is well known that the deterioration of concrete structures usually involves penetration of aggressive gases and/or liquids from the surrounding environment into the concrete followed by physical and/or chemical reactions within its internal structure, possibly leading to irreversible damage [2].

Also, for achieving major components of concrete like cement and aggregate material need to be produced and mined on massive scale and transported to cities which increasing energy consumption, air and sound pollution in cities. It is estimated that cement (Portland clinker) production alone contributes 7% to global anthropogenic CO_2 emissions, what is particularly due to the sintering of limestone and clay at a temperature of 1500 C [3]. So, from an environmental viewpoint, concrete does not appear to be a sustainable material [4]. Therefore, improvement of concrete properties such as compressive strength and permeability are the vital factors for increasing service life of concrete structures.

There are a variety of ways to reduce ingress of external agents in concrete, mainly by use of chemical, mineral admixtures and external coatings. But these are not permanent solutions and also they are not eco-friendly.

A novel strategy to enhance strength of cement based materials is biomineralization of calcium carbonate. Biomineralization is defined as a biologically induced precipitation in which an organism creates a local micro-environment, with conditions that allow optimal extracellular chemical precipitation of mineral phases [5]. Specific microorganism precipitates in calcium carbonate precipitation in the environment by producing the urease enzyme. Urease catalyzes urea to produce CO_2 and ammonia, resulting in an increase of pH in surroundings where mineral ions precipitate as $CaCO_3$ that plug pores and cracks in concrete. Recently, microbial mineral precipitation resulting from metabolic activities of some specific microorganisms in concrete to improve the overall behaviour of concrete has become an important area of research. At previous studies, Increases in compressive strength of cement mortar by different bacteria *Sporosarcina pasteurii* (18%) and *Shewanella* sp. (25%) were also reported by researchers [6], [7]. The increase in the matrix strength (for concrete made with bacterial cells) would have resulted in lesser mean expansion and would have eventually increased the overall durability performance of the concrete [8].

II. Material and Methods

A. Sampling and Isolation

For finding indigenous strains with the ability of carbonate calcium precipitation, sampling was done from loamy soil. All samples were poured into sterile glass container, transported to the laboratory and maintained their temperature in 4°C. The strains were isolated by using an

Manuscript received April 9, 2012; revised July 13, 2012.

A. Vahabi is with the Department of Construction Engineering and Management, Science & research Branch, Islamic Azad University, Tehran, Iran (e-mail: Vahabi_a85@yahoo.com).

K. Akbari Noghabi is with the National Institute of Genetic Engineering and Biotechnology (NIGEB), Karaj-Tehran highway, Pazhohesh Blvd, P.O. Box 14155-6343, Tehran, Iran (e-mail: Akbari@nigeb.ac.ir).

A. A. Ramezanianpour is with the Department of Civil & Environmental Engineering, Amirkabir University of Technology, Tehran, Iran (e-mail: aaramce@aut.ac.ir).

doi: 10.12720/jomb.1.1.36-38

enrichment culture technique. Also, Purified strain was investigated for preliminary identification.

B. Identification of Precipitates as $CaCO_3$

Properties of mortar specimen can be improved by plugging its pores with precipitations of some specific bacteria. The precipitation should be a stable mineral as calcium carbonate crystals. For achieving this purpose, bacterial precipitates of selected strain was analysed using Fourier-Transform InfraRed (FT-IR) spectroscopy by Perkin-Elmer Spectrometer (FT-IR GX 2000) to identify the genus of mineral. For the FT-IR study, precipitates were washed by repeated centrifugation and resuspension of pellet in distilled water to purify them. So dried precipitate powder was mixed with a KBr matrix (sigma) and tested. The spectra were in the range of 400-4000 cm^{-1} with 8 cm^{-1} resolution.

Generally, standard calcium carbonate FT-IR exhibits the major absorption peaks at 1418, 875 and 712 cm^{-1}.

C. Preparation of Mortar Specimens

The cement used was a commercially ASTM Type 1-425 portland cement. Chemical compositions of used cement are shown in Table I. Locally available clean, well-graded, natural river sand conforming to EN 196-1 was consumed as fine aggregate.

Mortar mixing was based on ASTM C109 standard. The ratio of sand to cement was 2.75 to 1 by weight, and water to cement ratio was 0.485. In this research, 50 mm test cubes were used with conforming to ASTM C109.

TABLE I: PERCENTAGES OF MAIN CHEMICAL COMPOSITIONS OF CEMENT

Cement component	(%)
CaO	65.34
SiO_2	20.83
Al_2O_3	4.34
SO_3	2.57
Fe_2O_3	2.21
MgO	2.17
L.O.I	0.91
K_2O	0.63

The specimens were prepared in three conditions, bacterial cubes, positive and negative control cubes. The isolated strain was cultured in a nutrient media including urea and calcium chloride and replaced with the mixing water in appropriate conditions in bacterial cubes. The positive control cubes (C.T+) were prepared in the same way, but only there was no strain in the media. Negative control specimens (C.T-) were prepared with distilled water according to standard conditions without any additives. After casting, all specimens were cured at room temperature (20 ± 2 °C) with the same conditions.

D. Compressive Strength Test

The mortar specimens were cured in conditions mentioned above (C) until compression testing. Cubes were broken at the age of 3, 7 and 28 days by using an automatic compression testing machine to determine compressive strength. All the experiments were performed in triplicate.

III. RESULTS

A. Isolation and Preliminary Identification of Selected Strain

After selecting the best strain according to its calcium carbonate production, the selected strain was distinguished as aerobic alkaliphilic spore-forming bacteria with the genus Bacillus named *Bacillus* sp. LS1.

B. Identification of Precipitate

Identification of precipitate was done by FT-IR spectroscopy. After complete drying of the sediment, FT-IR was done to identify the genus of produced precipitate by *Bacillus* sp. LS1. The results of identified precipitate are shown in Fig 1.

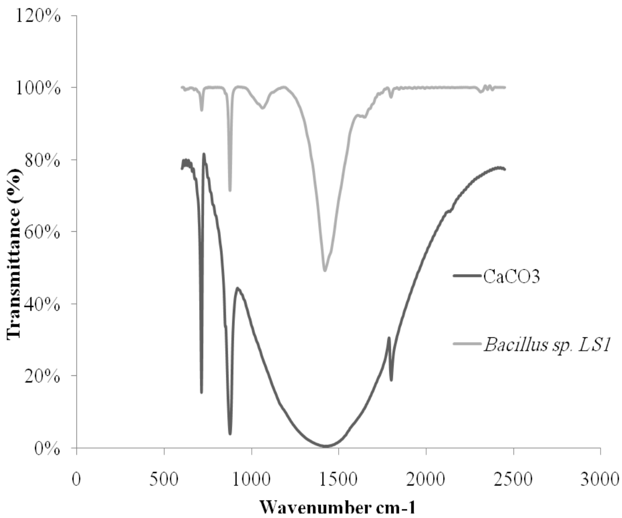

Fig. 1. FT-IR spectrum of the produced precipitate by *Bacillus* sp. Ls1 comparing with standard calcium carbonate.

The Fourier-Transform Infrared spectra of mineral precipitate are indicative of the presence of calcium carbonate. As a matter of fact, bacterial precipitate showed three main absorption peaks at 1418.83, 874.74 and 712.66 cm^{-1} that were conformed calcium carbonate standard peaks. Thus, selected isolate produced calcium carbonate crystals and could be an appropriate alternative strain for application in mortar specimens.

C. Compressive Strength

After breaking cubes by using an automatic compression-testing machine, compressive strength results of different cement mortar specimens were determined that are shown in Fig 2.

The compressive strength was significantly increased for mortar specimens that contained *Bacillus* sp. LS1. At 28 days, there was 15% and 12% improvement in the compressive strength of bacterial mortar compared with negative (C.T-) and positive (C.T+) control specimens respectively. Although, an improvement in the 28-day compressive strength was observed, there was less increasing in compressive strengths at 3 and 7 days of mortar cubes with all media.

The improvement of compressive strength by *Bacillus* sp. LS1 is probably derived from its $CaCO_3$ precipitation. The precipitation covers surfaces and plugs pores of cement–sand matrix [6]–[8].

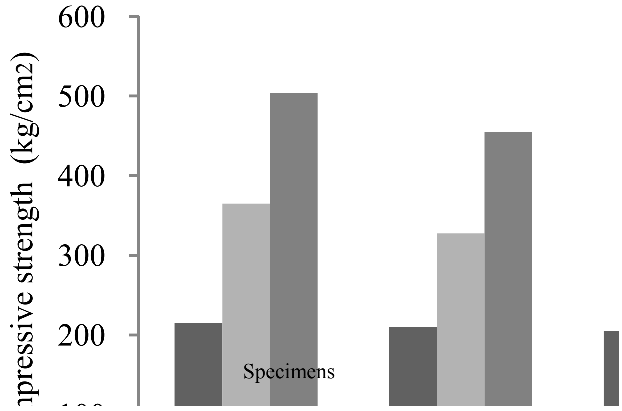

Fig. 2. Compressive strength results of bacterial mortar (LS1), positive control (C.T+), negative control (C.T-).

IV. Conclusions

At the end, results of research indicate that alkali-resistant spore-forming bacteria related to the genus Bacillus (*Bacillus* sp. LS1) represent appropriate alternative for application in concrete to improve the compressive strength. This strain could increase compressive strength near 15% in comparison to control specimens. In spite of ideal results, this biotechnology method should be investigated in other aspects such as durability, etc. However, it is obvious that application of this new technology will be a promising method to enhance concrete properties.

Acknowledgment

This work was financially supported by National Institute of Genetic Engineering and Biotechnology (NIGEB) and done with collaboration between NIGEB and Concrete Technology & Durability Research Center of Amirkabir University Labs.

References

[1] P. K. Mehta and P. J. M. Monteiro, "Concrete (Microstructure, Properties, and Materials)," *3nd Ed*, New York: McGraw-Hill, 2005, pp. 3-18.

[2] P. A. Claisse, H. A. Elsayad, and I. G. Shaaban, "Absoprtion and sorptivity of cover concrete." *J. Mater. Civil Eng*, vol. 9. pp. 105–110, 1997.

[3] E. Worrell, L. Price, N. Martin, C. Hendriks, and L. O. Meida, "Carbon dioxide emissions from the global cement industry," *Annu. Rev. Energy Environ*, vol. 26. pp. 303-329, 2001.

[4] G. P. Gerilla, K. Teknomo, and K. Hokao, "An environmental assessment of wood and steel reinforced concrete housing construction," *Build Environ*, vol. 42. pp. 2778–2784, 2007.

[5] W. A. Hamilton, "Microbially influenced corrosion as a model system for the study of metal–microbe interactions: a unifying electron transfer hypothesis," *Biofouling*, vol. 19, pp. 65–76, 2003.

[6] S. K. Ramachandran, V. Ramakrishnan, and S. S. Bang, "Remediation of concrete using micro-organisms," *ACI Mater. J*, vol. 98. pp. 3–9. 2001.

[7] P. Ghosh, S. Mandal, B. D. Chattopadhyay, and S. Pal, "Use of microorganism to improve the strength of cement mortar," *Cem. Concr. Res*, vol. 35, no. 10, pp. 1980-1983, 2005.

[8] V. Ramakrishnan, S. S. Bang, and K. S. Deo, "A novel technique for repairing cracks in high performance concrete using bacteria," in *Proc. Int. Conf. on High Performance*, *High Strength Concrete, Perth*, Australia, 1998, pp. 597–617.